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All About Space Annual

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All About Space Annual

The universe is full of secrets, from the mysteries of anti-matter to far-flung stars, and worlds that we're only just beginning to discover. In the **All About Space Annual 2019**, we've asked some of the world's top space scientists to share their amazing discoveries, research and theories to shed some light on those secrets. Discover the solutions to some of the greatest enigmas of the universe, see how we could conquer space, and learn new theories about the creation of our planet. Explore the Solar System and discover the technologies that may one day take us to its outer reaches and beyond. Learn about the mysterious galactic forces we could encounter on our journeys, and how we could use them to take us further and faster than ever before. Find out how we could one day live and work in space, and be amazed by the incredible inventions that will allow us to do so. This book is crammed with fascinating facts, stunning illustrations, and interviews with some of the world's top scientists, so continue to explore space and its far-flung celestial bodies now!

All About Space Annual

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"The cosmos is currently expanding"

EXCLUSIVE: ELON MUSK AND RICHARD BRAN

THEIR FIGHT

MA

It's the battle of the billionaires: two of the private space industry's most exciting companies - SpaceX and Virgin Galactic - go head-to-head and they're proving to be fiercely competitive

SON REVEAL

FOR

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© NASA; ESA; Virgin Plc Ltd; SpaceX; Adrian Mann

There are many similarities between Elon Musk and Richard Branson. For a start, both are serial entrepreneurs: Branson runs the British multinational Virgin Group which has interests in health, entertainment, publishing, travel and motorsport, while Musk is the co-founder of PayPal, the chairman of SolarCity and the chief executive of Tesla.

As a consequence, they are both billionaires, and very well-respected ones at that. Musk may only be 46-years old but, as a brilliant engineer with one of the greatest minds of a generation, he is often favourably compared to the equally genius (yet fictitious) Tony Stark of *Iron Man* fame. Branson is, at 67, 21 years his senior, yet he has proved to be equally worthy superhero in his endeavours. His penchant for balloon travel has seen him get into a few scrapes, but his frequent world-record attempts have seen him become the first man to fly over Mount Everest. Like Musk, however, Branson's current venture is set to take him even further still.

Having delivered cargo to the ISS, the booster lands successfully on the drone ship named Of Course I Still Love You

Branson and Musk are obsessed with space, and they are putting sizeable wedges of cash towards their respective ventures and ambitions. Branson has set up Virgin Galactic with the aim of encouraging passengers to stump up $250,000 for the undoubted pleasure of coasting towards the edge of space in its VSS Unity spacecraft. Musk founded SpaceX, which ultimately plans to populate the Red Planet, allowing anyone who can muster $200,000 the opportunity to embark on the potential one-way trip of a lifetime.

Yet it is here where the two men differ, and where their personal space race assumes a separate path - Musk's sights are set on the Red Planet, while Branson wants it all. "Elon is absolutely fixated on going to Mars, and I think it's his life mission," Branson says. "I am more interested in how we can use space to benefit the Earth, because the Earth is, in my opinion, extremely beautiful, and needs to be protected."

Like Musk, Branson has expressed interest in colonising the surface of the Red Planet - but he's willing to share with the CEO of SpaceX. "Mars is a big place. When we colonise Mars, Musk can have the west end, and we're gonna have the east end," he laughs. "There's room for us both." Speaking on resources for future settlers on Mars, Branson states: "I think there's plenty of frozen water, and those things, so we'll share the water." Musk, for his part, has indeed long argued that we must colonise the Red Planet. Should we seek to stay on Earth forever, he believes, "there will be some eventual extinction event." A case of do or die, then.

Of course, the natural end of our own planet is unlikely to happen any time soon, which is perhaps why Virgin Galactic is, for the time being at least, more concerned with letting would-be passengers have a bit of fun (as opposed to SpaceX's lofty aim of saving the human race). Branson hopes his company - which was founded in 2004 - is just 'months' away from sending himself - and soon after, his first paying passengers - into orbit, realising a dream which has so far been reserved of those hand-picked for their skills by the world's space agencies.

The most recent Unity test flight in July 2018 saw it reach soaring heights of over 170,000 feet and dizzying speeds of Mach 2.47. But in order to get to space, the Unity needs to double its current record, as space technically begins 62 miles (100km) up - so Virgin Galactic is still a way off.

Regardless, Branson is excited about his plans to personally go into space. He's undergone astronaut training, including fitness and centrifuge training - a similar regime undergone by the professionals before they are blasted off into space.

> "Elon is absolutely fixated on going to Mars, and I think it's his life mission"
>
> **Richard Branson**

Elon Musk VS

As two of the most successful entrepreneurs in

"Failure is an option here. If things are not failing, you are not innovating enough"

© Gregg DeGuire / Getty Images

Elon Musk

Net Worth:
$20.2 Billion

1983 Early talent
Having taken an interest in computer programming in his earlier years, at the age of 12, Musk used his new-found skills to create a game called *Blastar*, which he sold to a magazine for $500.

1992-1995 Graduated from university
Musk began his studies at Queen's University in Kingston, Ontario, Canada where he spent two years before moving to the University of Pennsylvania. He has two degrees: one in physics and one in economics.

1995-2002 Headed up PayPal
After founding Zip2, which licensed city guide software to newspapers, Musk set up the online banking company X.com. Following a merger it became PayPal, and Musk emerged as CEO.

2002-Present Founded SpaceX
Musk founded Space Exploration Technologies in a bid to slash the costs of launching spacecraft. Known as SpaceX, it works with NASA and aims to make travel to Mars affordable.

2004-Present Involvement with Tesla Motors
Having invested heavily in Tesla, Musk became chairman of the board. Today he is CEO and Product Architect, presiding over what promises to be an electric car revolution.

2016-Present Creates The Boring Company
Believing congestion is best relieved by sending traffic underground, The Boring Company's inexpensive tunnels tie in with Musk's concept of a hyperloop - transporting passengers in pressurised capsules in tubes.

Should Branson's estimates come true, then it means the 700 or so people signed up for the ride (reportedly including the actors Tom Hanks and Angelina Jolie) will enjoy several minutes of weightlessness in space sooner rather than later. They would go to greater heights than a plane could ever reach, and given that space has only been explored by 560 or so people so far, it would be something of a breakthrough. As Virgin Galactic points out on its website, it is opening space up to the rest of us (providing we have enough money). Musk is looking to do the same but on different terms: with Virgin you get to come back; with SpaceX, the journey to Mars is likely to be one way.

The late Professor Stephen Hawking claimed that we must look at colonising a new planet in the next 100 years, or suffer fatal future consequences. That would be music to Musk's ears as he seeks a band of space-faring pioneers determined to make the human race multi-planetary. "However, we will not establish self-sustaining colonies in space for at least the next hundred years, so we have to be very careful in this period," warned Hawking.

Musk wants to ferry people in a pressurised section of what he used to call the Mars Colonial Transporter but is now referred to as the Big Falcon Rocket, or BFR for short. Eventually, he hopes the journey time to the Red Planet will be just 30 days, but the idea is that the spacecraft would carry tons of cargo and building material and enable the colonisers to produce the necessary infrastructure and home comforts. "We'll have 450 tons of luggage and all of the unpressurised cargo to build everything from iron foundries, pizza joints, you name it," he says.

SpaceX is working with NASA, having docked their Dragon spacecraft at the International Space Station

Virgin Galactic's Spaceport America in New Mexico is the world's first purpose-built commercial spaceport

VSS Unity, built by The Spaceship Company, made its first free flight in December 2016, piloted by Mark Stucky and Dave Mackay

© SpaceX; Virgin Group Ltd

Richard Branson

the world, they have the impressive CVs to match

Richard Branson

Net Worth: $5.1 Billion

1968 Set up a magazine

Although Branson struggled with school and dropped out at 16, his entrepreneurial flair was evident early on. In 1968, he launched *Student* magazine, making money by selling advertisements.

1970-Present Created Virgin

After selling music by mail order, Branson opened his first record shop on Oxford Street in London, calling it Virgin because he was a beginner at business. A record label followed.

1984-Present Launched Virgin Atlantic

Branson became a thorn in British Airways' side when he launched a rival airline, Virgin Atlantic, quickly establishing itself by the decade's end.

1986 Smashed a world record

Branson crossed the Atlantic in a powerboat for more than three days, but completed the journey two hours faster than the previous record-holder. He has made many other record attempts since.

1993 Received an honorary degree

Having recognised his growing accomplishments, Loughborough University made him an honorary Doctor of Technology. In 2000, he was knighted by Charles, Prince of Wales for his 'services to entrepreneurship.'

2004-Present Launched Virgin Galactic

Not content with launching Virgin Trains in 1997, Branson went a step further and created Virgin Galactic, which aims to open up space travel to anyone able to stump up the cash.

"You don't learn to walk by following rules. You learn by doing and by falling over"

© Ray Tamarra / Getty Images

The Dragon is a reusable spacecraft developed by SpaceX. It's launched by the Falcon 9 rocket

Keen on conquering space, Branson hasn't let returning to the lunar surface escape his notice. "Why not have a hotel in space?" he asks. "How fantastic would it be to go and spend a week in a space hotel?"

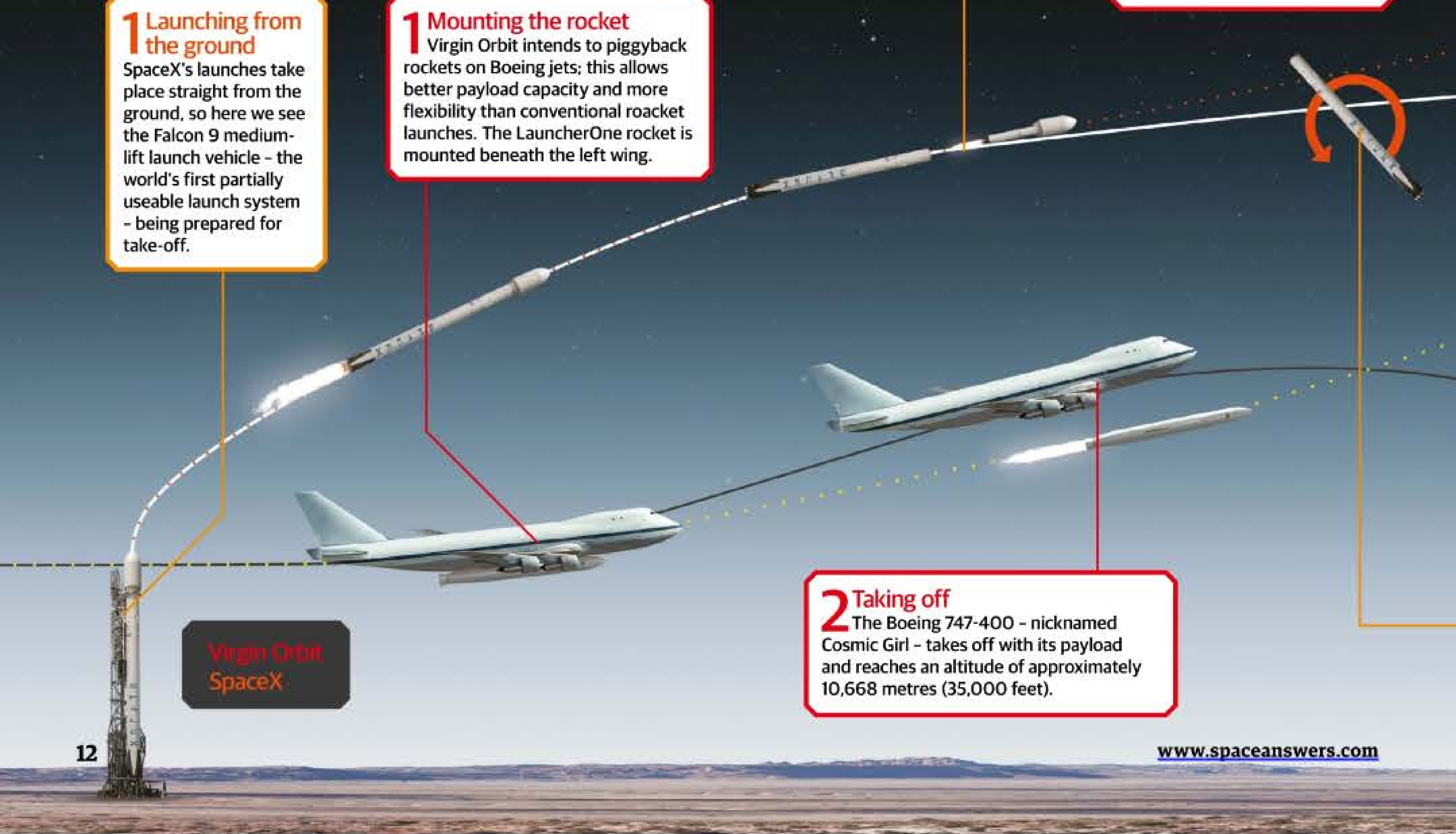
With the two billionaires keeping their eyes locked on space, **All About Space** asked Musk whether he was thinking bigger than Branson. "He did name his firm Virgin Galactic. That's pretty big," Musk replied. "It's a bit like your name is Giant and you're actually quite small." He then added: "Technology is not really his whack, you know."

Branson counteracted this claim and said he hoped to prove Musk wrong. He added that his own strength was surrounding himself with brilliant people (and indeed, in 2010, Virgin Galactic secured the services of George Whitesides, NASA's former chief of staff, as its chief executive). He also claimed his technology would eventually be able to transport passengers across the Earth in spaceships, and

Virgin Orbit vs SpaceX

Branson and Musk also want to send private satellites into space on behalf of companies and governments

- Virgin Galactic began working on the LauncherOne concept in 2007.
- LauncherOne has a target price of $10 million per flight.
- It can carry up to 300 kilograms (661 pounds) into Sun-synchronous orbits.
- It can also carry up to 500kg (1,100lbs) into a low-Earth orbit.
- After 16 months of modification work, 747-400 was complete.



1 Launching from the ground

SpaceX's launches take place straight from the ground, so here we see the Falcon 9 medium-lift launch vehicle – the world's first partially useable launch system – being prepared for take-off.

1 Mounting the rocket

Virgin Orbit intends to piggyback rockets on Boeing jets; this allows better payload capacity and more flexibility than conventional roacket launches. The LauncherOne rocket is mounted beneath the left wing.

2 Beginning its ascent

As the rocket ascends into space, the two stages are separated. The first stage, which incorporates nine Merlin engines, can begin preparing to come back to Earth.

2 Taking off

The Boeing 747-400 – nicknamed Cosmic Girl – takes off with its payload and reaches an altitude of approximately 10,668 metres (35,000 feet).

3 Releasing the rocket

LauncherOne is then released, at which point it fires the NewtonThree – a single main stage engine – for three minutes. It produces about 327 kilonewtons (73,500 pounds) of thrust.

put thousands of small satellites into space: two of the ways Branson says his company's missions will benefit people intent on remaining on this planet. Perhaps more interesting is the notion discussed on Virgin Galactic's website that "space is not only important for the future of transportation, commerce and science; it's also important for the future of imagination." This is where a line may be drawn between the aims of Virgin Galactic and that of SpaceX in this very modern space race.

Whereas Musk wants to save humankind by physically transporting as many as a million people to Mars on a total of 10,000 trips over the course of 40 and 100 years (the capacity of the spacecraft is 100), Branson wants to do the same by altering mental attitudes. He talks of the Overview Effect, felt by astronauts when they go into space: "Having left the Earth and seen it from thousands of miles away, they gain new perspective on their home planet, and see how tiny the differences are and how great the shared bonds," he writes. "They return with a profound desire to change the world for the better."

Musk appears to think differently. He feels that humans on Earth will only strive to resolve the problems they have created when they realise the mess they're in is real. In that sense, he isn't overly concerned about shaping minds right now, believing it will happen naturally and in due course. "The sustainable energy future, I think, is largely inevitable, but being a space-faring civilisation is definitely not inevitable," he says. Attempting to save humans, wherever they may end up, is more of a priority than purely trying to make Earth alone better, it seems.

> "He did name his firm Virgin Galactic. It's a bit like your name is Giant and you're actually quite small" **Elon Musk**

Even so, both Musk and Branson are interested in bettering lives through faster transport, which is why they are also locked in a side-battle over hyperloop technology. The brainchild of Musk, hyperloop involves whizzing passengers from A to B on Earth in pressurised capsules. However, while the chief of SpaceX's The Boring Company seeks to build hyperloop tunnels underground, Hyperloop One, in which Branson has invested, prefers tunnels to be overground. Different approaches and different mindsets appear to be at play at every step.

Given their interests overlap, the main question is why the two business moguls haven't sought to work together? That may go back to 2015, when Branson teamed up with Alphabet CEO Larry Page to develop

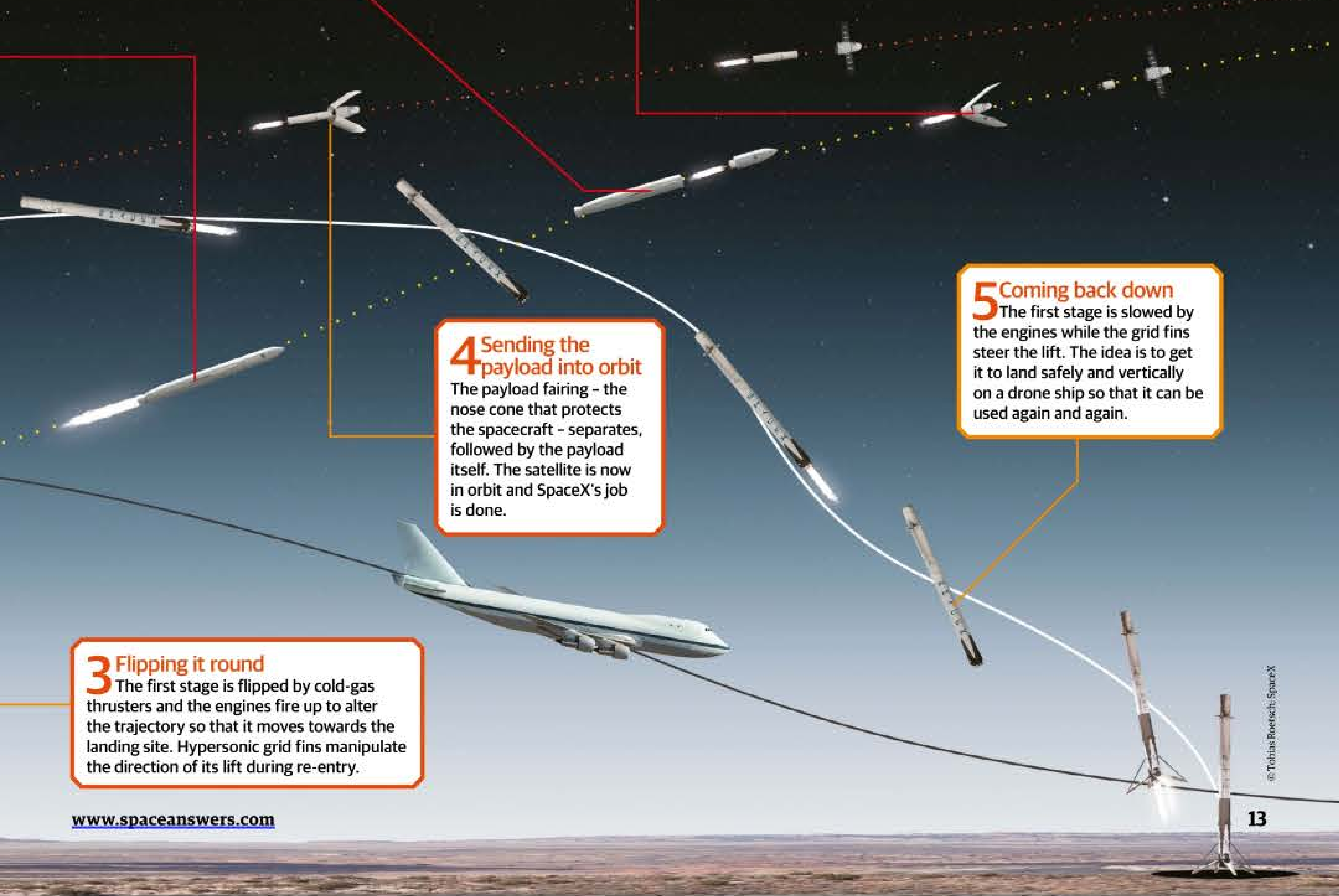
4 Shipping the satellite

Now a single upper-stage engine – the NewtonFour – kicks in. It has 22 kilonewtons (5,000 pounds) of thrust, using RP-1 kerosene and liquid oxygen for fuel. This carries the satellite into orbit.

5 Releasing the payload

After executing multiple burns for around six minutes, LauncherOne deploys the satellite into its orbit. Its job is now done, allowing the two LauncherOne stages to be deorbited and the plane to land at a predetermined airport.

- SpaceX began working on Falcon 9 in 2006.
- It can launch a payload for a minimum of $62m, according to its website.
- Falcon 9 is capable of carrying 8,300 kilograms (18,300lbs) into geostationary transfer orbit.
- It can also carry 22,800 kilograms (50,265lbs) to low-Earth orbit.
- Falcon 9 made history by delivering the Dragon Spacecraft into orbit to the ISS in 2012.



4 Sending the payload into orbit

The payload fairing – the nose cone that protects the spacecraft – separates, followed by the payload itself. The satellite is now in orbit and SpaceX's job is done.

5 Coming back down

The first stage is slowed by the engines while the grid fins steer the lift. The idea is to get it to land safely and vertically on a drone ship so that it can be used again and again.

3 Flipping it round

The first stage is flipped by cold-gas thrusters and the engines fire up to alter the trajectory so that it moves towards the landing site. Hypersonic grid fins manipulate the direction of its lift during re-entry.

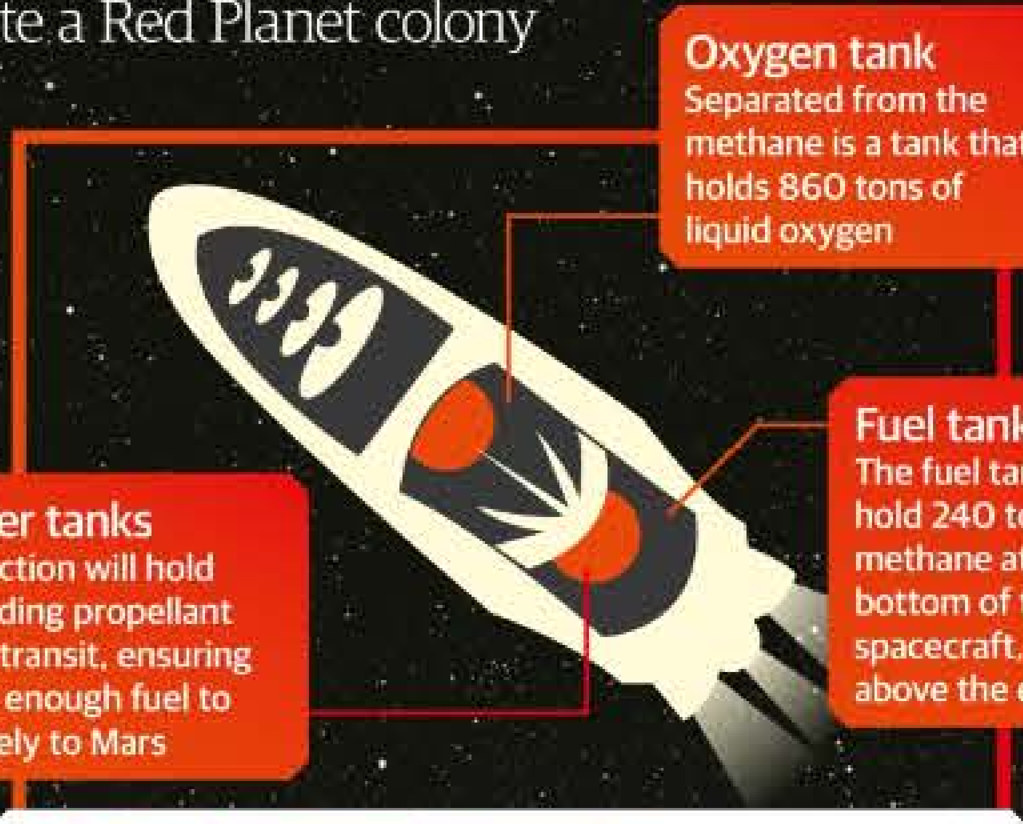
© Tobias Roetsch; SpaceX

"Mars belongs to Elon"

How Elon Musk is planning to create a Red Planet colony

1. Build a really big rocket

SpaceX is creating the Big Falcon Rocket (BFR) – a rocket larger than any that have gone before. Weighing a total of 4,400 tons at liftoff, and standing at 106 metres (347ft) tall and nine metres (30ft) in diameter, it will have a liftoff thrust of 5,400 tons. It will also have 31 Raptor engines and be fully reusable, helping to dramatically reduce costs. SpaceX hopes to have it ready for use in the early 2020s.



Oxygen tank
Separated from the methane is a tank that holds 860 tons of liquid oxygen

Fuel tank
The fuel tank will hold 240 tons of methane at the bottom of the spacecraft, just above the engines

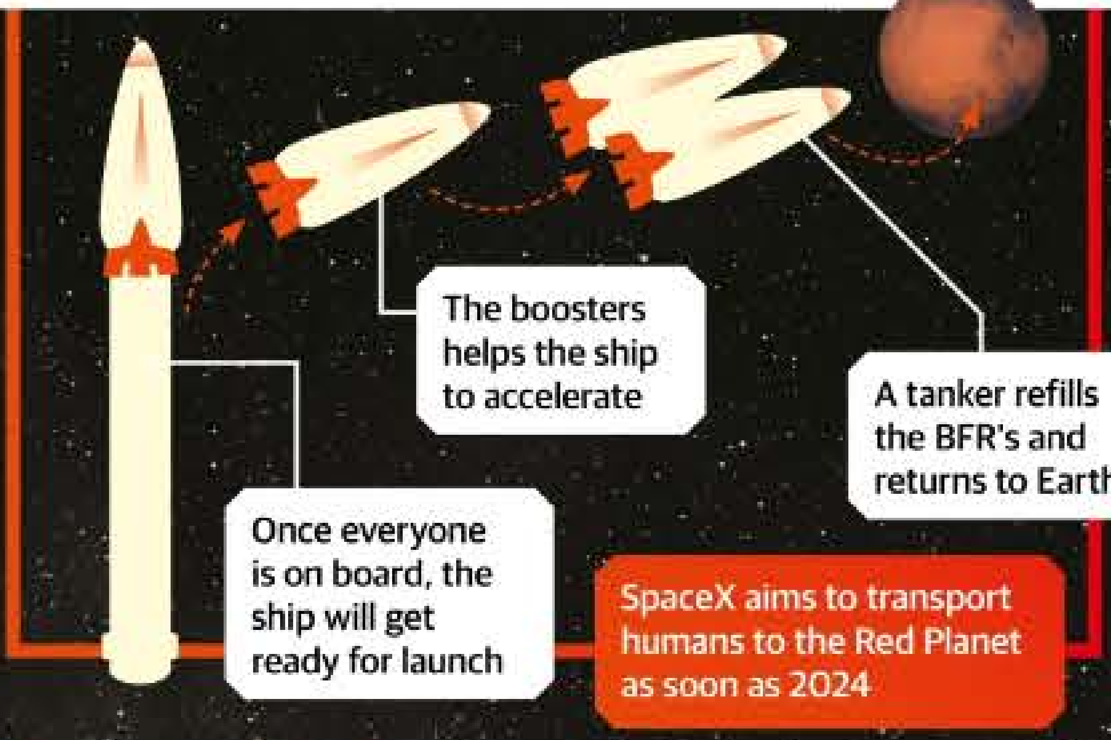
Header tanks
This section will hold the landing propellant during transit, ensuring there's enough fuel to get safely to Mars

2 Create a humongous spaceship

At the tip of the BFR is the payload: the section where passengers will stay and where the cargo will be stored. It will have 40 cabins and large common areas along with a galley and a solar storm shelter, plus lots of entertainment: it's a long journey after all. SpaceX says the cabin will be pressurised to a volume of $825m^3$, which is greater than that of an A380 aeroplane. It's thought 100 people will complete each journey.

3. Get it into space

The BFR will take off vertically, propelled skywards by its 31 engines. When it gets through the Earth's atmosphere, the booster will detach and power back to Earth. The spaceship will then continue on its way, making use of the fuel tank that holds 240 tons of methane and the oxygen tank that holds 860 tons of liquid oxygen. There are six raptor (two types) engines on the spacecraft itself.



The boosters helps the ship to accelerate

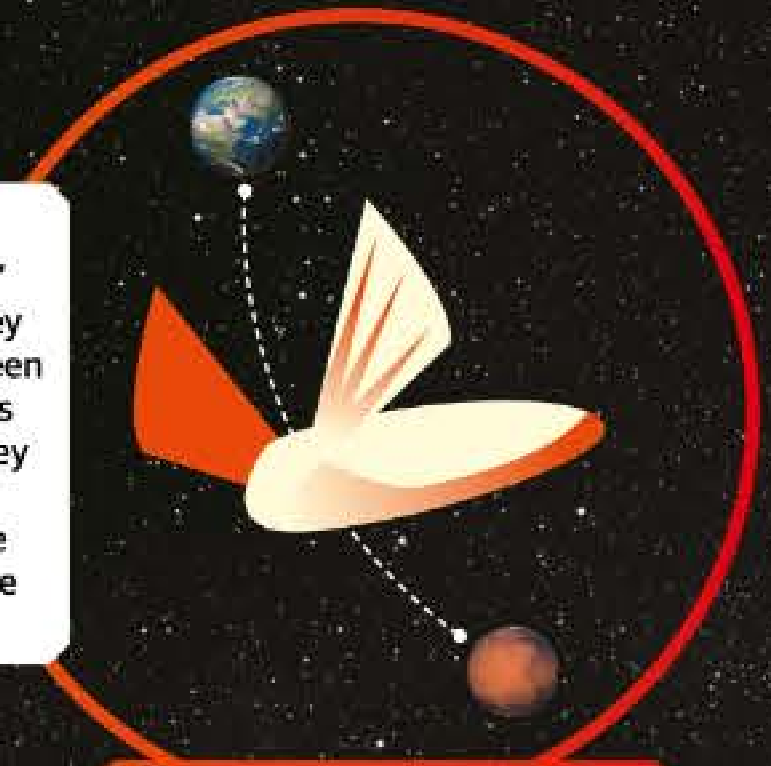
A tanker refills the BFR's and returns to Earth

Once everyone is on board, the ship will get ready for launch

SpaceX aims to transport humans to the Red Planet as soon as 2024

4. Make the long journey

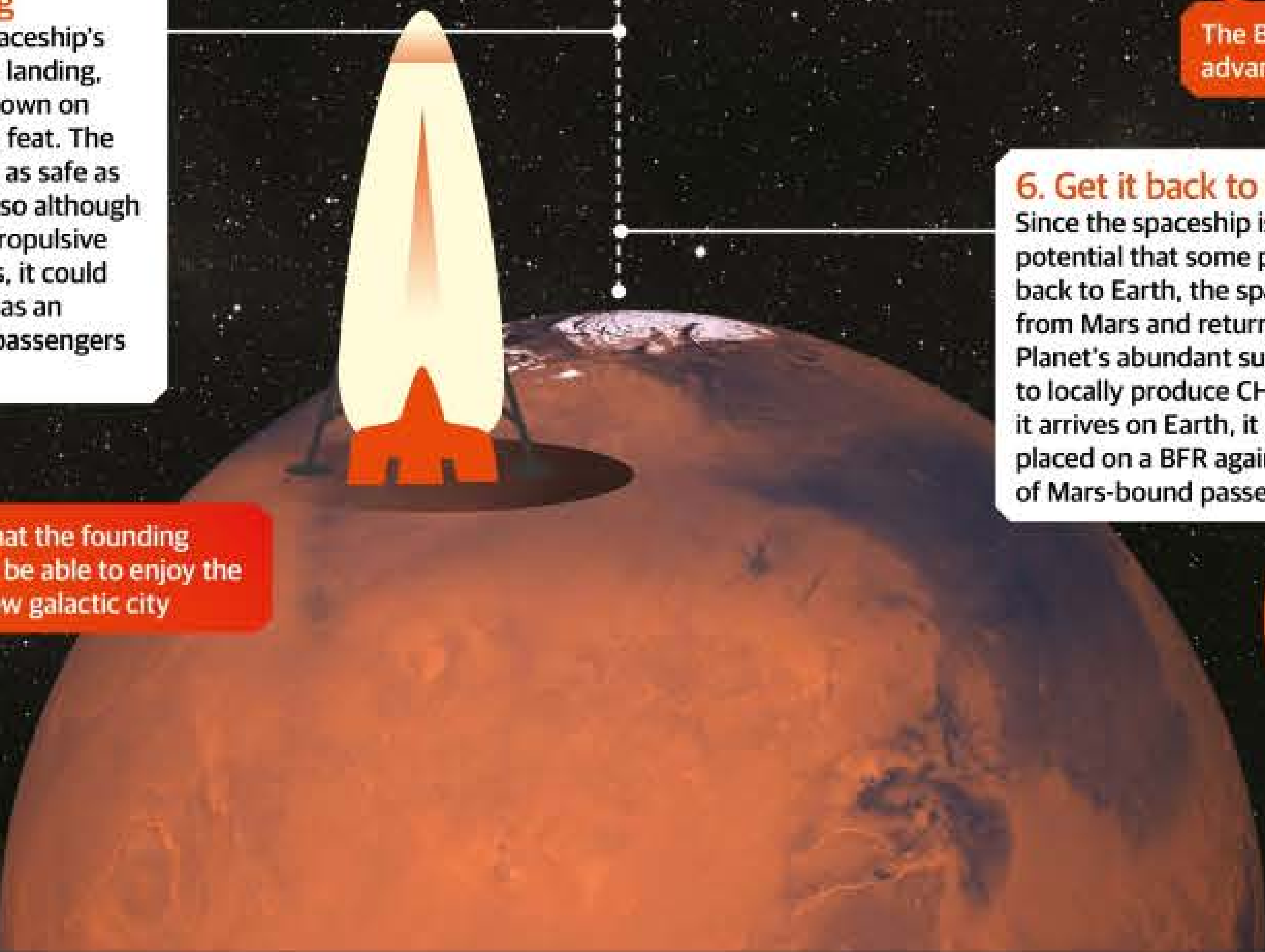
Cries of "are we nearly there yet?" are inevitable, because the journey to Mars will take anywhere between three and six months. Solar panels will be deployed during the journey and this will power some of the much-needed entertainment. The views should be spectacular as the Red Planet looms into view.



The BFR will make use of advanced heat-shield technology

5. Ensure a safe landing

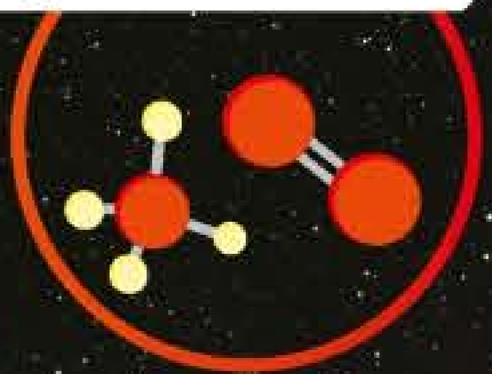
When it gets to Mars, the spaceship's legs will deploy for a vertical landing, but it's fair to say touching down on the surface will be no simple feat. The aim, says Musk, is to make it as safe as landing a commercial plane, so although it will land under the retro-propulsive thrust of two Raptor engines, it could also do it with one if there was an engine failure. Time for the passengers to disembark.



The idea is that the founding Martians will be able to enjoy the spoils of a new galactic city

6. Get it back to Earth

Since the spaceship is reusable and there is potential that some people may want to come back to Earth, the spacecraft needs to take off from Mars and return. The idea is to use the Red Planet's abundant supply of CO_2 and water ice to locally produce CH_4 and O_2 propellant. Once it arrives on Earth, it will be checked over and placed on a BFR again, ready for the next group of Mars-bound passengers.



a space-based internet that would use inexpensive, low-power satellites for launch by Virgin Galactic. It appears Branson wanted Musk on board, but "was saddened that Elon didn't consider working with Larry and me."

Instead, SpaceX and Virgin Galactic are both charting their own separate paths, and they are both proving to be highly successful at it. In October 2017, Virgin Galactic was given a major boost thanks to $1 billion in funding from Saudi Arabia, authorised by its Crown Prince Mohammed bin Salman. "This will enable us to develop the next generation of satellite launches and accelerate our programme for point-to-point supersonic space travel," Branson says.

This is, in some sense, another sub-race in itself, because SpaceX is also hoping its rockets will enable point-to-point Earth travel too. Musk has suggested future passengers could wing their way from New York to Shanghai in as little as 39 minutes at over 18,000 kilometres-per-hour (11,372 miles-per-hour).

Branson is also looking to go toe-to-toe with SpaceX in bagging commercial and government contracts. He is doing so with a new space-centred company called Vox Space, based in southern California. It's aim, according to its website, is to "provide the national security community of the USA and allied nations with the ability to launch services for small satellites bound for low-Earth orbit". Another spin off, Virgin Orbit, will also launch services for small satellites, but those government contracts are a lucrative business. SpaceX offers rockets capable of carrying 22,680-kilograms (50,000 pounds) to low-Earth orbit, compared to the 181-kilograms (400-pound) capacity of Vox. It is also designing a spacecraft for NASA.

While Virgin Galactic and SpaceX are not competing with each other to be the first to Mars, they are going head-to-head in other areas. So, while, SpaceX isn't planning on launching its first mission to Mars before 2022 (a timescale even Musk readily admits is "aspirational"), their other plans should come to fruition sooner. Branson is set to win the personal space race, however, since he is very much on course to be the first of the pair to journey into space.

However, he admits that the Virgin Galactic project has been one of his greatest challenges yet. It has already claimed the life of test pilot Michael Alsbury when the first version of the SpaceShipTwo, the VSS Enterprise, disintegrated over the Mojave Desert in 2014. Virgin Galactic has since received its operating license from the US Federal Aviation Authority in 2016.

Musk, on the other hand, is far less likely to be on his spacecraft to Mars in the early stages, although he does want to go eventually. "I'd have to have a really good succession plan [for SpaceX], because the likelihood of death is very high," he explains. He is understandably worried about not seeing his children grow up and he frets that investors may decide, in his absence, not to continue with the Mars plan. But rather morbidly, he has said that he wants to die on Mars: "I can't think of anything more exciting than going out there among the stars," he smiles.

One thing's for sure, though, these are fascinating times for both Musk and Branson, and indeed the rest of the world. It's heartening for space enthusiasts to see that the pair are so deeply passionate about space and it's exploration. The astounding levels of investment in their respective astronomical endeavours truly brings them together, and there's no suggestion that a bit of healthy competition is a bad thing. With so many clever scientists and engineers working on the various projects, and two driven bosses, we will inevitably reach new heights in our quest to explore the universe. The future is indeed looking bright.

> "I can't think of anything more exciting than going out there among the stars"
>
> **Elon Musk**

© SpaceX

Hyperloop technology was originally an idea coined by Musk, with Branson investing in the American company Hyperloop One in 2017

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THIS MISSION WILL FIND EARTH 2.0

NASA's new planet-hunting satellite will revolutionise our understanding of planets around other stars – and statistics suggest that it should find some worlds very similar to ours

Written by Giles Sparrow

© Tobias Roetsch

The search for 'exoplanets' - worlds orbiting distant stars - has come a long way since the first such objects were confirmed in the mid-1990s. Today thousands of alien worlds are known or suspected, with each new satellite or technique offering fresh insights, which leads to the detection of many new planets. However, fundamental questions remain unanswered, and our experiments produce discoveries that are inevitably biased towards certain type of planets that are easy to detect.

Now, a small satellite, the Transiting Exoplanet Survey Satellite (TESS), promises to look at the sky in a whole new way, which could finally answer some key questions - particularly when it comes to small planets like Earth. Over the next two years, the team behind TESS hope that it will create the most comprehensive catalogue so far of planets orbiting bright and nearby stars.

TESS has been a long time coming, as Dr Stephen Rinehart, the mission's project scientist at NASA's Goddard Space Flight Center, recounts: "The project started out as an independently funded development that MIT [Massachusetts Institute of Technology] was doing with some private donors [Google in particular provided early investment]. After missing out on selection for NASA's Small Explorer satellite program in the late 2000s, the TESS team realised that the spacecraft would work better as a full-scale Explorer mission, and Goddard was brought on board."

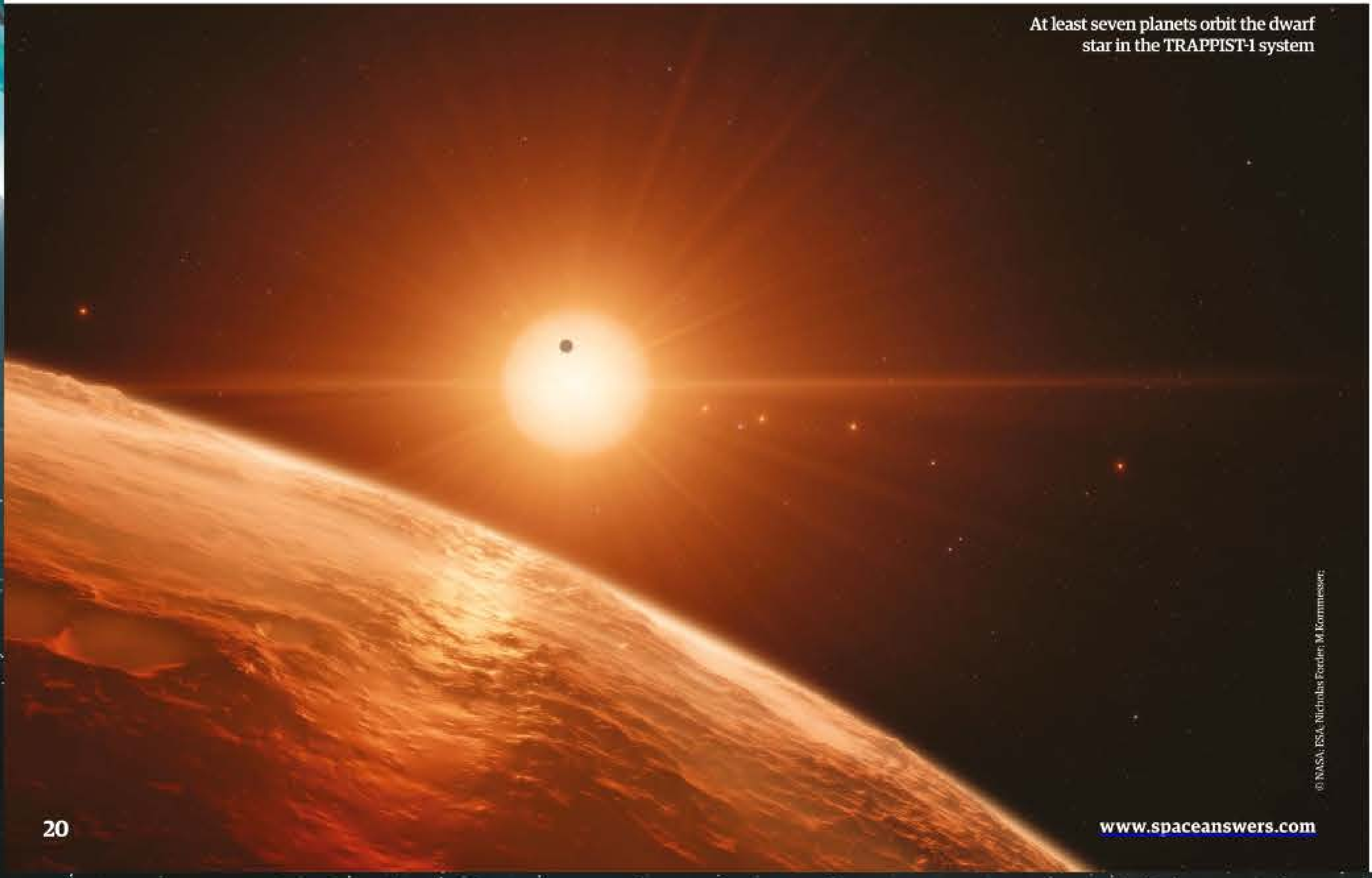
Rinehart's role involves day-to-day collaboration with the mission's principal investigator (PI), Dr George Ricker, and deputy PI Dr Roland Vanderspek, both at MIT's Kavli Institute for Astrophysics and Space Research. "Roland was actually my undergraduate thesis adviser, shall we say, a while ago," he recalls, "so I've known these guys since I was an undergrad. When Goddard got involved, it was clear that TESS needed a NASA project scientist, and George asked for me to join the team in that role. We submitted our proposal around the beginning of 2011, and in 2013 we got the go ahead to actually start building. As we speak we're two months and one day from our planned launch date."

As its name suggests, TESS will detect planets using the so-called 'transit method', measuring tiny dips in starlight created by orbiting planets. "You can see the principle at work in our own Solar System," explains Dr Rinehart. "There are some great videos of Venus transiting the Sun in 2004 and 2012. If you have a planet orbiting a star, and its orbit happens to be aligned with your line of sight, then the planet will pass in front of the star. In our Solar System that means that we can occasionally see Venus as a black dot tracking in front of the Sun. For more distant stars of course, we can't resolve the little black dot, but the planet still blocks a certain amount of light from the star - and the exact amount depends on how big the planet is."

That small amount of blocked-out light is the key not only to finding planets, but also to estimating their sizes: "If we were looking at our own Solar System from, say, ten-light-years away, if Earth passes in front of the Sun, it blocks out about 0.01 per cent of the Sun's light. Jupiter on the other hand blocks out about one per cent."

Searching for planets using the transit method involves making frequent measurements of a star's exact brightness and pinpointing moments when that brightness suddenly dips and then recovers. If the dips repeat in a regular pattern, this confirms the planet's orbital period - its year. For example, if a star dips in brightness by one per cent every 20 days, astronomers can not only tell that the exoplanet has a 20-day year, but can also estimate its size at about 1/10th the diameter of the star (and therefore blocking out 1/100th of its visible surface during transits). It's simple in principle, but requires high-precision measurements, an uninterrupted, undistorted view of the sky and lots of patience - all factors that make it a tough call for

> "The next step in exoplanet research is to start characterising individual planets, not just counting them" **Stephen Rinehart**



At least seven planets orbit the dwarf star in the TRAPPIST-1 system

© NASA; ESA; Nicholas Forder; M Kornmesser;

Evolution of an exoplanet hunter

TESS is just the latest in a series of satellites that have revolutionised our ideas about alien worlds

Kepler

Launch date: 7 March 2009

NASA's Kepler satellite was designed to carry out a long-term survey of a single area of the sky. Although a failure in its pointing mechanism led to the original mission goals being cut short, engineers redesigned the satellite to continue useful planet-hunting work. So far it has yielded over 2,000 confirmed exoplanets.

Spitzer

Launch date: 25 August 2003

This NASA spacecraft was put to work on the hunt for exoplanets after its hardware was tweaked. NASA's Sean Carey, the manager of the Spitzer Science Center at Caltech in Pasadena, California, said: "We never even considered using Spitzer for studying exoplanets... It would have seemed ludicrous back then."

TESS

Launch date: 20 March 2018 (no later than June 2018)

TESS will carry out the first comprehensive transit survey of bright stars across the sky and is predicted to discover tens of thousands of new worlds, including about 2,000 Earth-like exoplanets.

Hubble Space Telescope

Launch date: 24 April 1990

The venerable Hubble Space Telescope was the first large optical telescope in orbit. Although it was not designed to hunt for exoplanets it has laid the foundations for many of the specialised missions that have since followed. The telescope has also offered us important insights into exoplanets found by other means.

CHEOPS

Launch date: End-2018

A collaboration between the European Space Agency and Switzerland, CHEOPS (CHaracterising ExOPlanets Satellite) will use a larger telescope than TESS to target stars already known to have transiting planets, producing more accurate information about their size, density and other characteristics.

JWST

Launch date: Spring 2019

Currently scheduled for launch next year, NASA's enormous infrared space telescope and successor to Hubble should offer new insights into the way that Solar Systems form around young stars, and is expected to be able to provide direct images of many exoplanets for the first time.

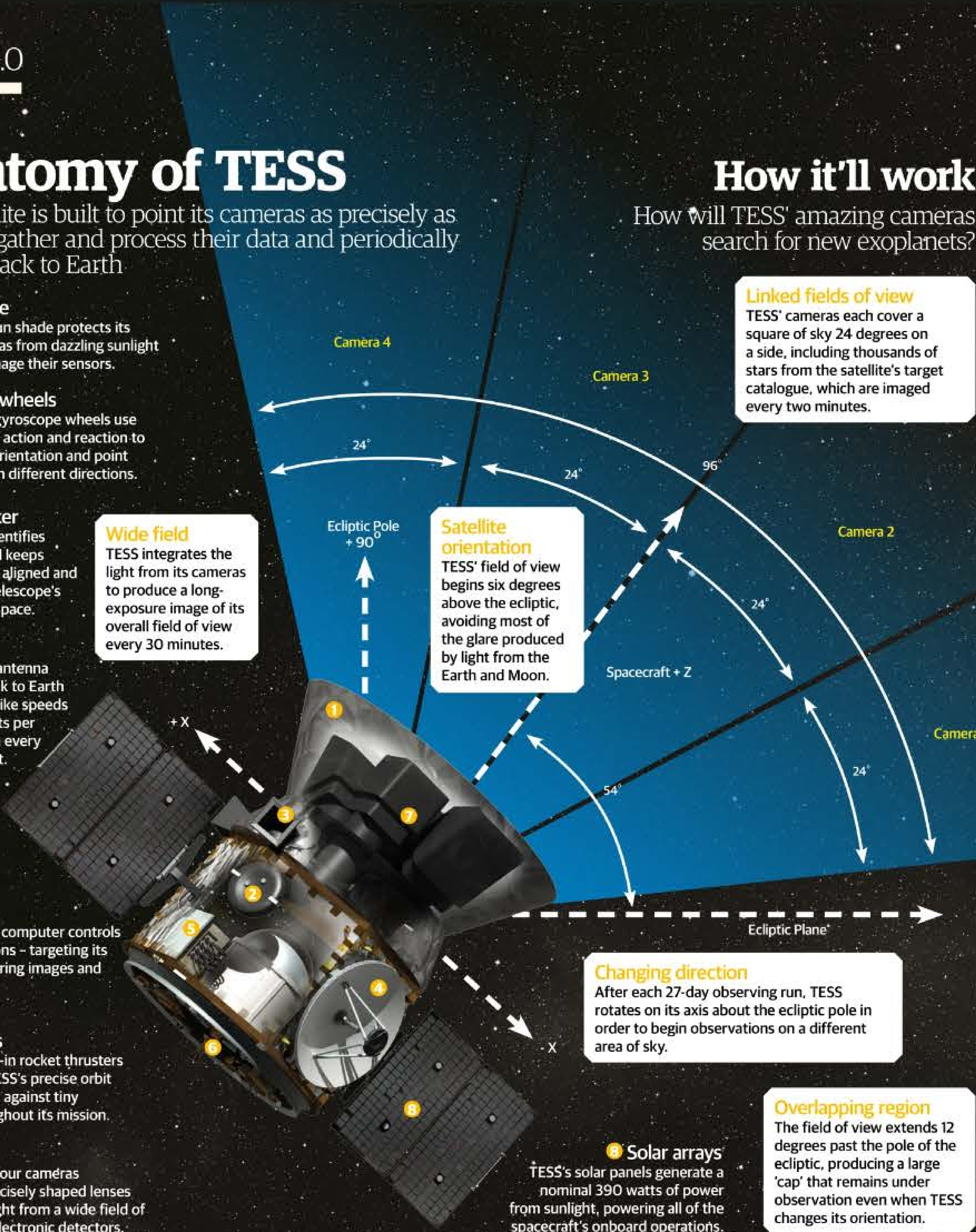
WFIRST

Launch date: Mid-2020s

Now under full development by NASA, the Wide-Field Infrared Survey Telescope (WFIRST) will carry a coronograph designed to precisely block the dazzling light of stars without affecting the much fainter light of their planets. This could reveal details such as their surface temperatures, composition and atmospheric gases.

Anatomy of TESS

The satellite is built to point its cameras as precisely as possible, gather and process their data and periodically beam it back to Earth



① Sun shade
TESS's outer sun shade protects its delicate cameras from dazzling sunlight that could damage their sensors.

② Reaction wheels
Four spinning gyroscope wheels use the principle of action and reaction to adjust TESS's orientation and point the telescope in different directions.

③ Star tracker
This camera identifies guide stars and keeps them precisely aligned and maintain the telescope's orientation in space.

④ Antenna
The satellite's antenna sends data back to Earth at broadband-like speeds of 100 megabits per second once in every two-week orbit.

⑤ Master computer
TESS' onboard computer controls all the operations – targeting its cameras, acquiring images and storing data.

⑥ Thrusters
Five small built-in rocket thrusters help finalise TESS's precise orbit and maintain it against tiny changes throughout its mission.

⑦ Cameras
Each of TESS' four cameras uses seven precisely shaped lenses to direct starlight from a wide field of view onto its electronic detectors.

⑧ Solar arrays
TESS's solar panels generate a nominal 390 watts of power from sunlight, powering all of the spacecraft's onboard operations.

Wide field

TESS integrates the light from its cameras to produce a long-exposure image of its overall field of view every 30 minutes.

How it'll work

How will TESS' amazing cameras search for new exoplanets?

Linked fields of view

TESS' cameras each cover a square of sky 24 degrees on a side, including thousands of stars from the satellite's target catalogue, which are imaged every two minutes.

Satellite orientation

TESS' field of view begins six degrees above the ecliptic, avoiding most of the glare produced by light from the Earth and Moon.

Changing direction

After each 27-day observing run, TESS rotates on its axis about the ecliptic pole in order to begin observations on a different area of sky.

Overlapping region

The field of view extends 12 degrees past the pole of the ecliptic, producing a large 'cap' that remains under observation even when TESS changes its orientation.

TESS' targets

Earth-like planets

TESS' postage-stamp images of selected stars should capture the small changes in brightness triggered when small Earth-like planets, such as those in the TRAPPIST-1 system, pass in front of their stars.

Giant gaseous worlds

TESS' wide-field images are expected to capture up to 20,000 new transiting planets around bright stars. It has been suggested that most of these are likely to be gas giants in tight orbits around their stars, similar to HD 189733b.

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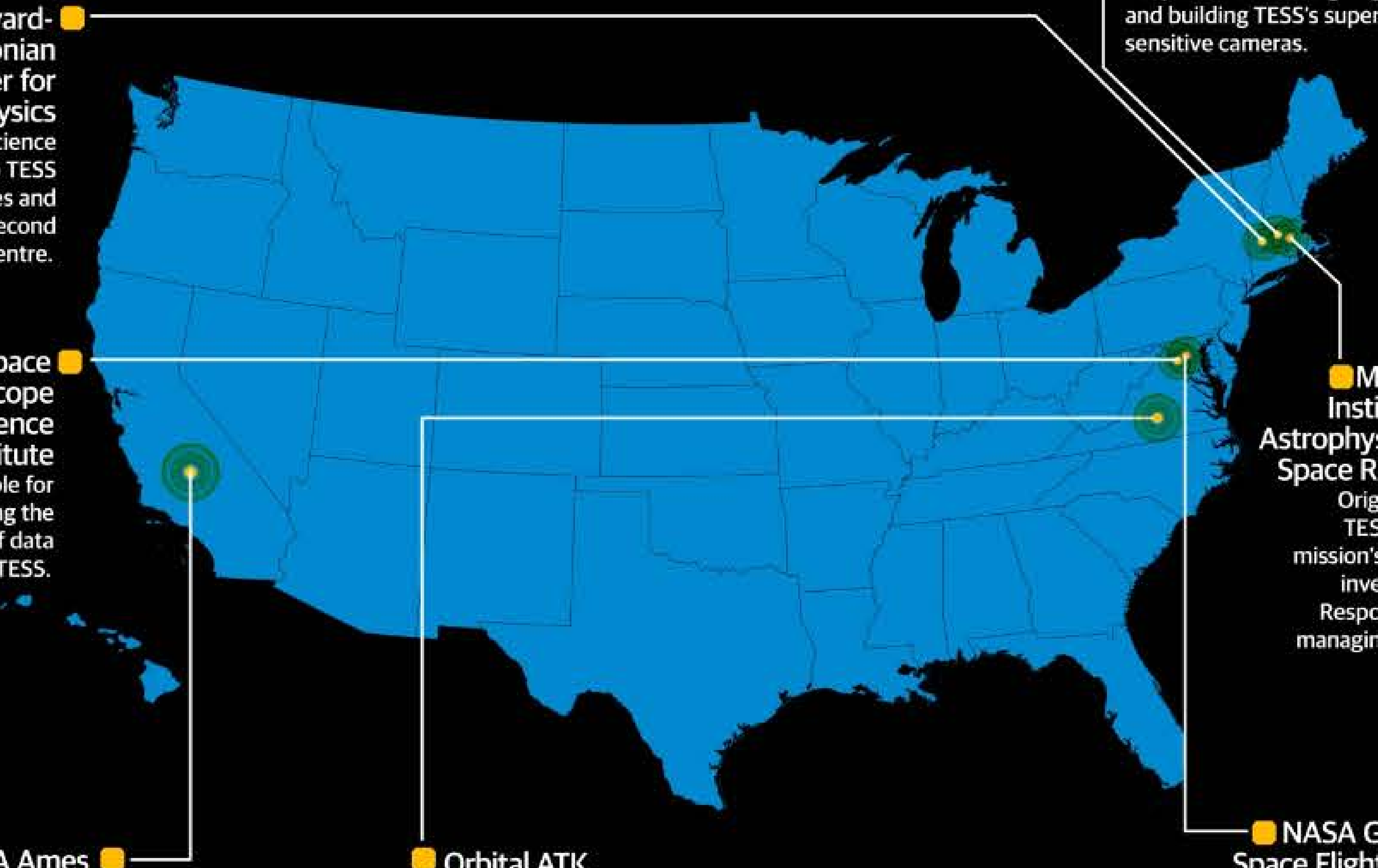
Who's involved?

TESS is a collaboration – but who does what?



Harvard-Smithsonian Center for Astrophysics
Manages science follow-up to TESS discoveries and acts as a second science centre.

Space Telescope Science Institute
Responsible for archiving the wealth of data from TESS.

NASA Ames Research Center
Developed TESS's science pipeline.

Orbital ATK
Provides the main satellite 'bus', integrates and tests the TESS instruments, runs mission operations centre.

MIT Lincoln Laboratory
Responsible for designing and building TESS's super-sensitive cameras.

MIT Kavli Institute for Astrophysics and Space Research
Originators of TESS and the mission's principal investigators. Responsible for managing mission science.

NASA Goddard Space Flight Center
Manages the TESS mission, including engineering, safety, communication and public engagement.

most Earth-based telescopes, but an ideal task for orbiting satellites.

The most famous use of the transit method so far has been in NASA's hugely successful Kepler satellite. Launched in 2009, Kepler was designed to stare at a single crowded region of sky, continuously monitoring the brightness of more than 150,000 stars and looking for any tell-tale dips. Before Kepler, only a handful of exoplanets had been detected using transits – many more were known from the radial velocity (RV) technique, the first exoplanet-hunting tool to be developed in the mid-1990s.

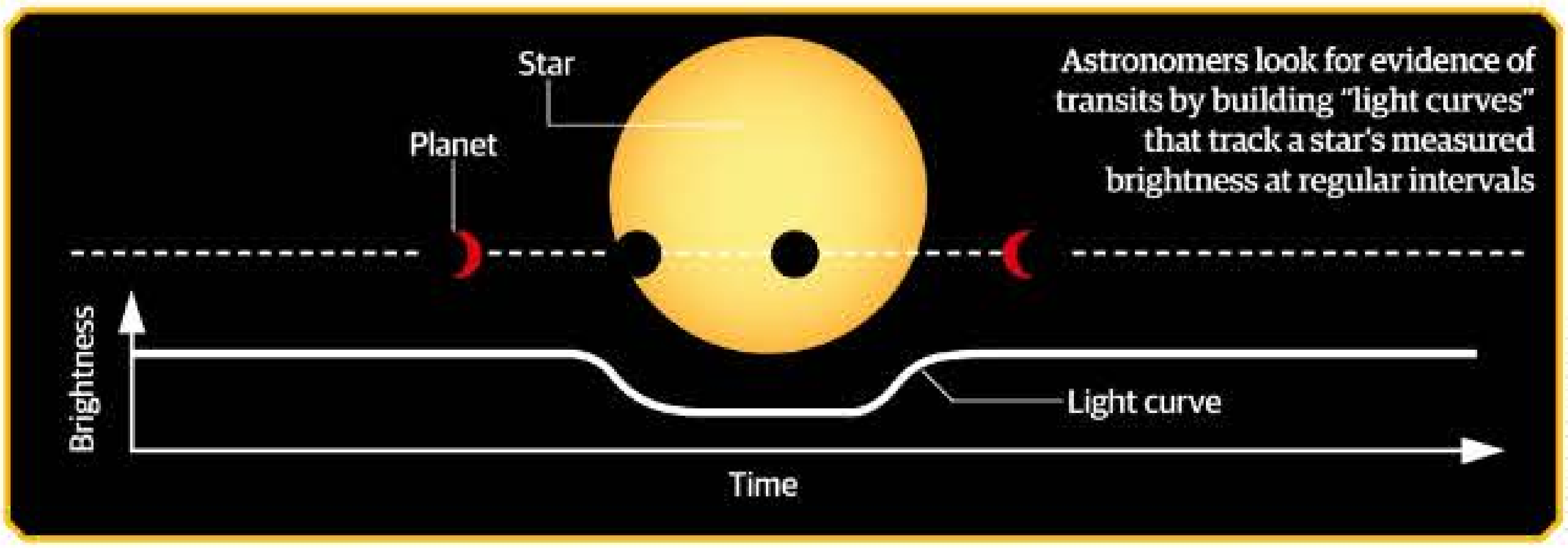
RV relies on analysing a star's rainbow-like spectrum to detect minute shifts in the wavelength of its light, created when a star with an orbiting planet is pulled slightly towards and then away from Earth by the planet's mass. Although it is biased towards detecting giant planets with enough mass to influence the movement of their star, in principle RV allows planets to be found in any size of orbit. It also provides clues to a planet's minimum mass (though not an absolute measurement on its own).

The transit method, in contrast, is biased towards planets in tight orbits around their stars – simple geometry means that the bigger a planet's orbit is, the greater the chance that the planet can circle its star while never crossing its face as seen from a given direction in space. On the other hand, transits allow astronomers to find small planets whose gravitational tug is probably too small to make an obvious impression on their star's light spectrum.

"Before Kepler, we had no idea what percentage of stars had an Earth-like planet around them," points out Dr Stephen Rinehart. "We just didn't have enough of them to reach any conclusions, because finding those small planets is really hard with the radial velocity method." Kepler's hugely successful mission, however, identified thousands of transiting planets, offering a startling insight into just how common broadly Earth-like exoplanets probably are. Inevitably, though, its success has given rise to new and even more challenging questions.

"The next step in exoplanet research is to start characterising individual planets," states Rinehart. "Not just counting them and knowing that they're there, but measuring features such as their masses

> "Before Kepler, we had no idea what percentage of stars had an Earth-like planet around them"
>
> **Stephen Rinehart**



Astronomers look for evidence of transits by building "light curves" that track a star's measured brightness at regular intervals

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and perhaps even detecting their atmospheres. If you know the orbital period from transits, that can help you identify changes in the radial velocity data even if it's a really weak signal. But you still need to have a good spectrum, and for that you need relatively bright stars."

Kepler's long, deep stare across the galaxy netted a huge number of transits for its survey of the broad exoplanet population, but very few of its targets were bright enough to provide useful data when their light was smeared out by a spectroscope. As a result, the RV technique's usefulness is limited to just a handful of Kepler's discoveries.

TESS, however, takes a different approach, designed specifically to find stars that lend themselves to follow-up RV measurements and other observations. Instead of harvesting vast numbers of faint stars in a single direction, the satellite will conduct a relatively shallow survey of bright stars across the entire sky. As Rinehart explains: "We're looking for planets transiting stars within a couple of hundred light years as opposed to a couple of thousand for Kepler, so on average the stars are between 30- and 100-times brighter."

In order to carry out its survey, TESS carries a set of four cameras pointing in different directions on a single plane, like evenly spread fingers. Each camera has a 24 x 24-degree field of view (huge in astronomical terms), so together the cameras cover a field of 24 x 96 degrees at any time. Developed at MIT's Lincoln Laboratory, the cameras are relatively small, with each light-gathering lenses just ten centimetres (four inches) in diameter, but they use highly sensitive state-of-the-art detectors to deliver a pin-sharp 64-megapixel image of the sky.

Dr Rinehart takes up the story: "When TESS is observing, it looks at a single field of view for 27 days. That field extends from six degrees above the ecliptic plane [the plane of Earth's orbit around the Sun, cluttered with nearby Solar System objects including planets and asteroids] to 12 degrees past the ecliptic pole. By tiling 13 of these observing strips over 27 days we can cover almost an entire hemisphere of the sky, including continuous coverage of the area around the pole. We start in the southern hemisphere, and then in the second year of the mission we flip around and look at the northern hemisphere. That way we cover nearly the entire sky, apart from a 12-degree band around the ecliptic itself."

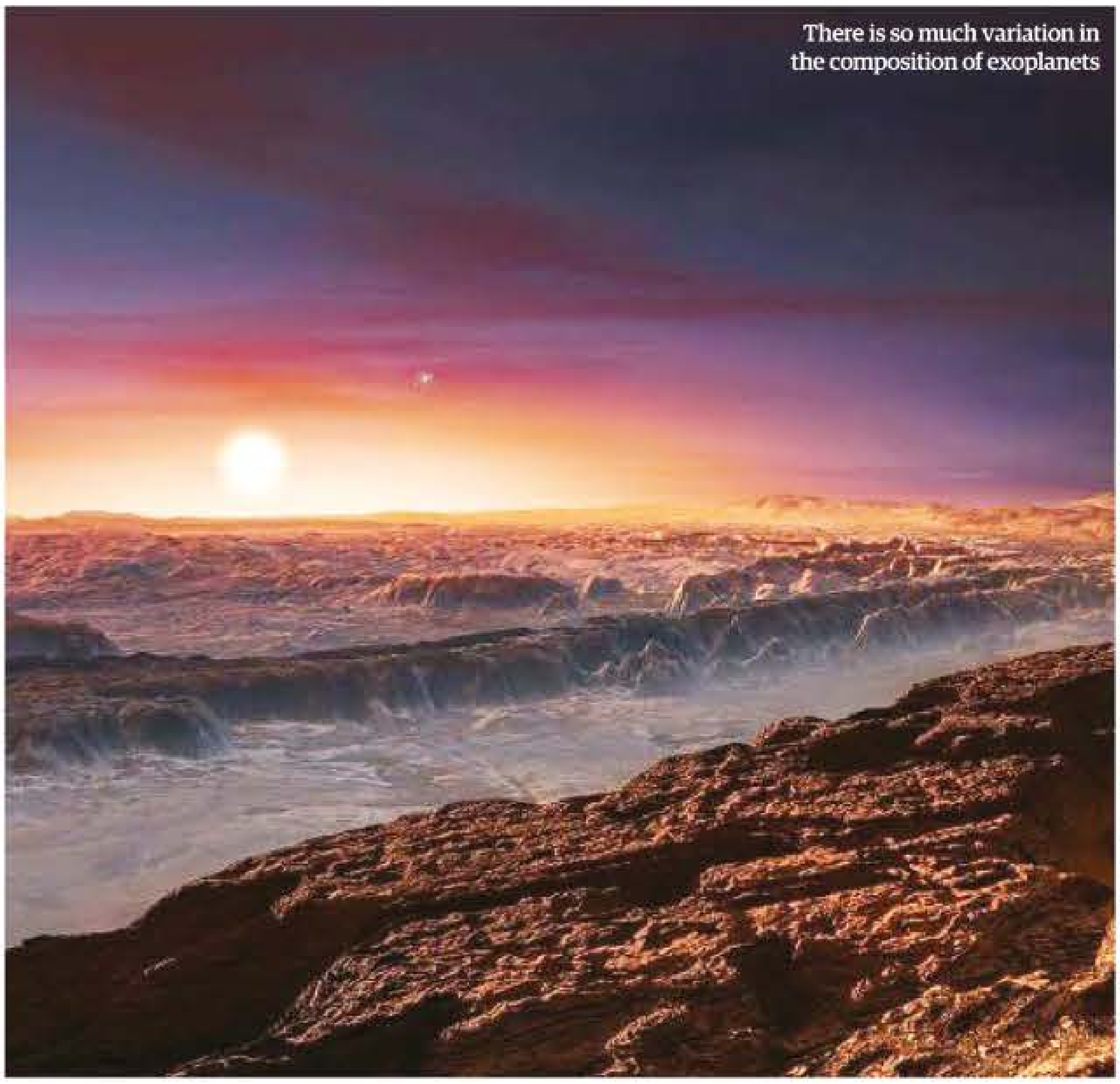
> "There's the potential for TESS to produce some really interesting data about the late stages of planet-forming discs" **Stephen Rinehart**

TESS's onboard systems carry out the first step in turning raw camera images into useful transit-hunting data. The satellite is programmed with a catalogue of around 200,000 preselected stars, and the camera electronics extract 'postage stamps' of each target star on the list every two minutes; each orbit produces 10,000 postage stamps. Once in each 13.7-day orbit around Earth, this data is transmitted to the ground, where it can be converted into a light curve of each star's brightness over time.

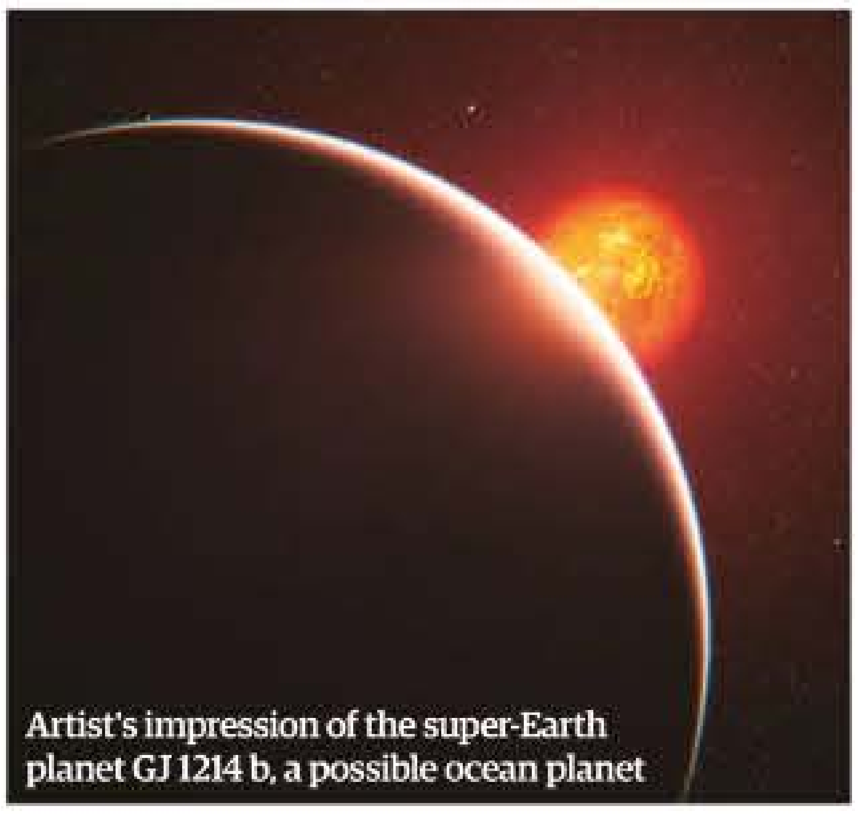
In addition, every 30 minutes the cameras deliver a long-exposure image of their entire field of view. "That data's going to be really interesting," enthuses Rinehart. "The primary goal of TESS is to find small planets, so when we select our target catalogue we're aiming for stars where we could hope to find those kinds of planets. There are certain stars, larger ones for instance, where we couldn't hope to detect an Earth-sized planet with this telescope, so we don't bother wasting the two-minute data from it, but those stars will still be on the full images."

This means that while statistics suggest the mission may find about 2,000 Earth-like planets in the postage-stamp data, the full-frame exposures could reveal another 20,000 larger planets around other stars. "With Kepler there's a limited number of planets suitable for follow-up observations, but with TESS there should be a glut," predicts Rinehart. "One of the challenges for the project is trying

TESS is expected to catalogue around 500 Earth-sized and super-Earth planets



There is so much variation in the composition of exoplanets



Artist's impression of the super-Earth planet GJ 1214 b, a possible ocean planet

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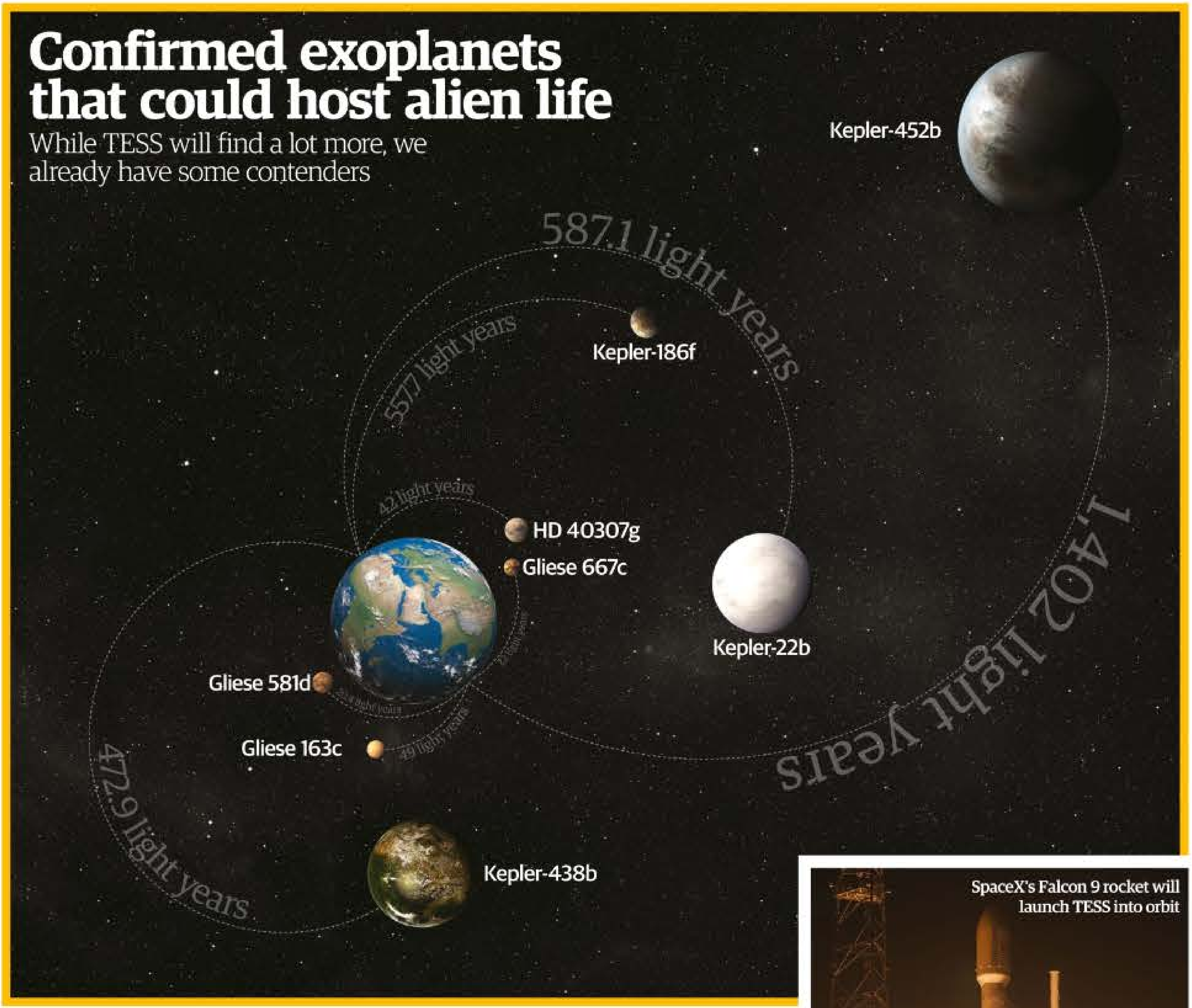
Confirmed exoplanets that could host alien life

While TESS will find a lot more, we already have some contenders



SpaceX's Falcon 9 rocket will launch TESS into orbit

to help organise the community for doing those follow-up observations - we don't want four people all deciding to do follow-up work on the same target at the same time!"

But while TESS's primary goal is to deliver a flood of new planetary discoveries, that's not the only reason for astronomers to look forward to it. Regular 30-minute snapshots of the sky will capture changes in the brightness and appearance of celestial objects that have nothing to do with transits. Variable and pulsating stars, repeating stellar explosions called recurrent novae and the violent cores of active galaxies are just some of the objects where TESS could help shed new light, and that's without considering the possibility of completely surprising discoveries.

"The Kepler team like to point out that half the papers generated by their mission have nothing to do with exoplanets," reflects Stephen Rinehart. "It was never planned, it's just that people in the community have gone 'Hey, there's something else cool that I can do with this data.' With TESS, there's no proprietary period - we're going to get the data out there as quickly as we can, and the astronomical community is going to be able to go to town just looking through it for new and interesting things."

As for Rinehart himself, once TESS is safely in orbit and delivering its data he's keeping an open mind as to what comes next. "Most of what I do is building stuff - my focus has always been on what questions need answering and what can I build to answer them. My primary science interests have been in star formation and the evolution of planetary systems, and I think there's the potential for TESS to produce some really interesting data about the late stages of planet-forming discs. I've not really had the time to plan out what my research programme is going to look like yet, but some people are going to do a lot of interesting stuff with that data regardless, and hopefully I'll get to be involved in it."

ENCEL

A NEW PLACE FOR LIFE?

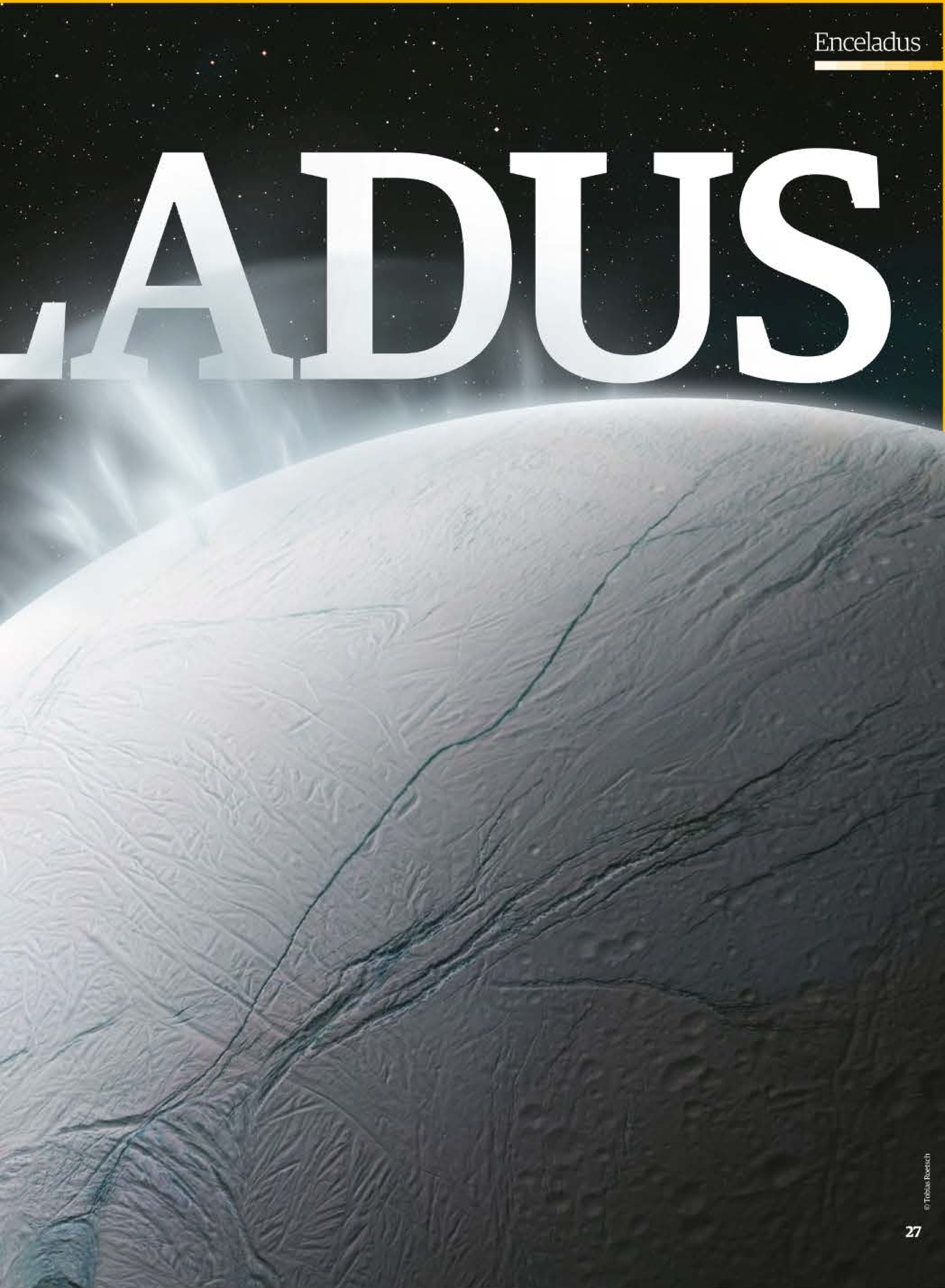
Forget Mars, this frozen member of Saturn's family of moons could hold the key to organisms beyond the confines of Earth

Reported by Lee Cavendish

Enceladus is Saturn's sixth-largest moon and a world that is seven-times smaller than our natural satellite. It orbits Saturn at around 1.2 billion kilometres (746 million miles) away from Earth and reflects nearly 100 per cent of the sunlight that hits its surface. Very little was known about this icy world but that changed when NASA's Cassini spacecraft performed its first flyby of Enceladus and imaged its south pole. This revealed plumes of ice and water vapour erupting into space, and Cassini returned about 2.5 years later on 12 March 2008.

This was when scientists realised that this moon has a hidden, rich and surprising interior that could make it a keen target for astrobiological study. Now it is considered one of the - if not *the* - most exciting prospects for extraterrestrial life and a potentially habitable environment elsewhere in our Solar System. "As the evidence continues to grow, Enceladus becomes a more and more attractive candidate to look for life. For me, Enceladus is the most likely place to look for life beyond Earth," Dr Linda Spilker, the project scientist for Cassini, explains to **All About Space**.

LADUS



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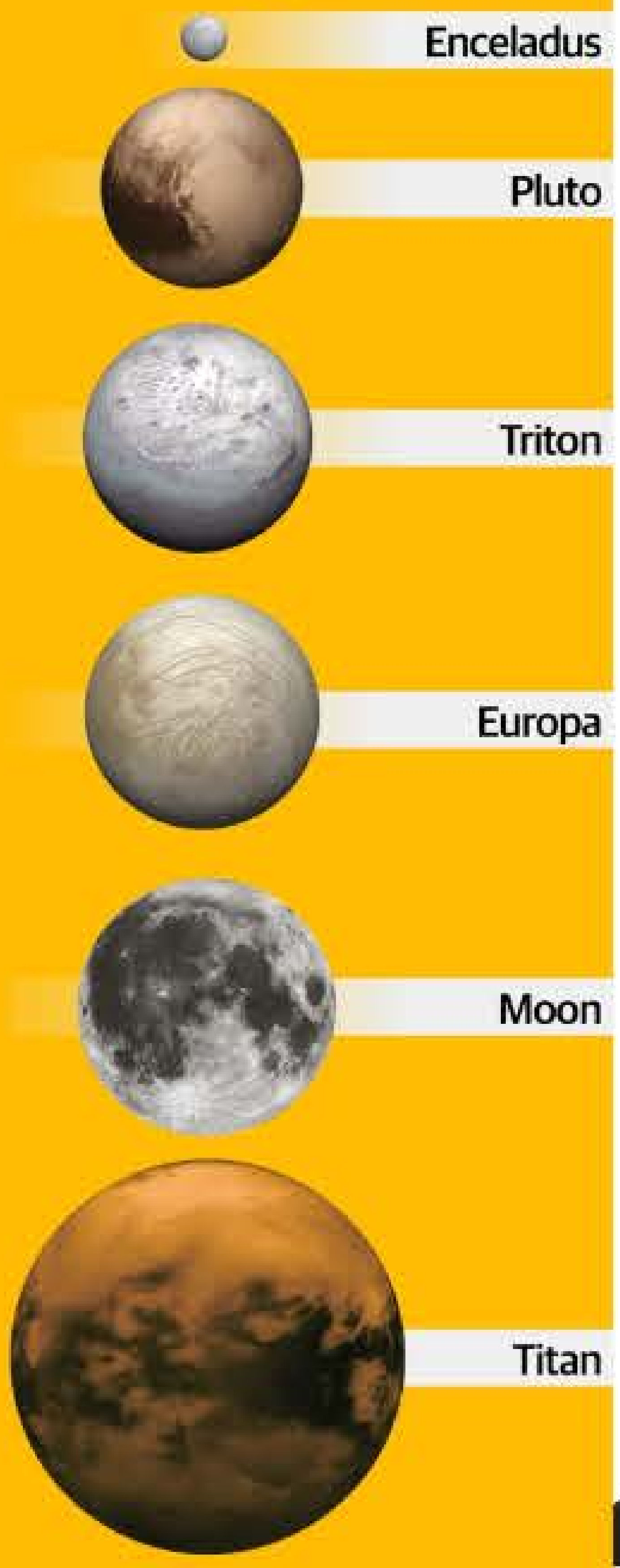
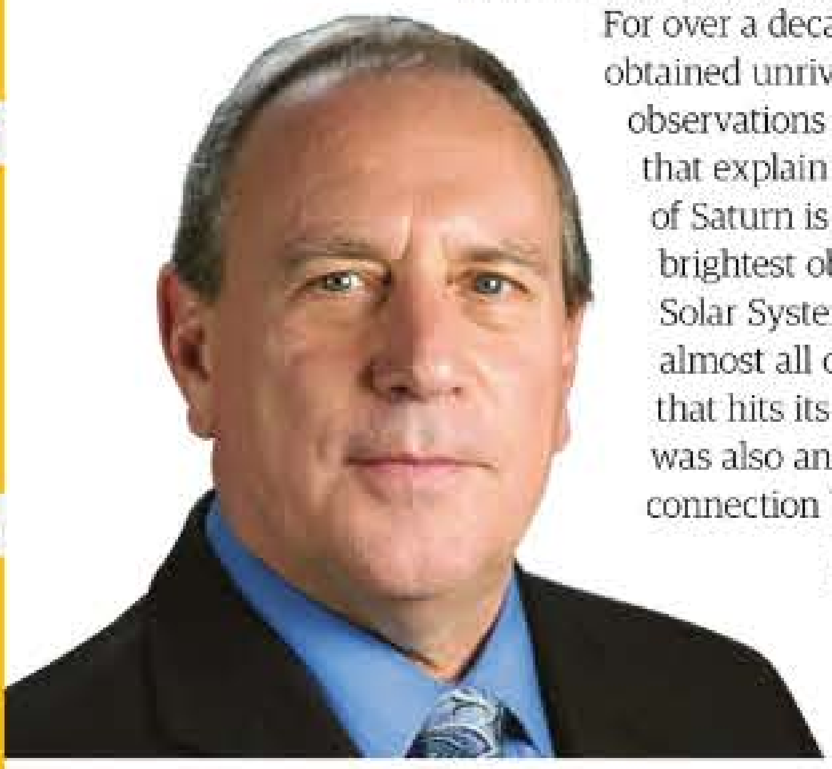
Small Solar System size comparison



Over a decade later, scientists have recently been reanalysing the data collected by the Cassini spacecraft. This study has discovered that the molecules that constitute these erupting space plumes are more complex and exciting than previously thought. Courtesy of Cassini's two scientific instruments, the Cosmic Dust Analyzer (CDA) and the Ion and Neutral Mass Spectrometer (INMS), the identification of these complex, carbon-rich organic molecules now tick another box when it comes to the criteria of the requirements for life.

"Enceladus checks all the boxes for habitability: liquid water, organic material for use as building blocks and a source of chemical energy. Furthermore, the material vented into space from its ocean provides an easy means to investigate the ocean below," Dr Hunter Waite of the Southwest Research Institute in San Antonio, Texas, United States and also principal investigator of Cassini's INMS instrument, tells **All About Space**. "Europa [Jupiter's fourth largest moon] may be just as interesting from an astrobiological perspective, or more so, but we do not have the data to draw that conclusion yet. Given our present state of knowledge, Enceladus is the most practical place to look for extant life outside of Earth."

For over a decade, Cassini obtained unrivalled observations of Enceladus that explain why this moon of Saturn is one of the brightest objects in the Solar System, reflecting almost all of the sunlight that hits its surface. There was also an unknown connection between the moon and Saturn's E-ring which needed to be answered as well. When Cassini arrived at the scene in 2005, its suite of finely tuned instruments and equipment had the ability to resolve the unexpected icy water jets spewing out from the 'tiger-stripes' surface features at the south pole of Enceladus from afar. Cassini also had the ability to fly through these plumes, gathering unique data about them and revealing a mixture of volatile gases, water vapour, carbon dioxide and carbon monoxide, as well as organic materials. The density of organic materials was about 20-times denser than expected.


Dr Hunter Waite is the principal investigator of the INMS instrument

Astronomers back on Earth have been thoroughly examining the data over the course of this mission. Early analysis of Enceladus' plumes revealed the presence of a subsurface ocean about ten kilometres (six miles) deep beneath an ice shell about 30 to 40 kilometres (19 to 25 miles) thick. There was also evidence for the presence of hydrothermal vents, which are cracks on the planet's core releasing heat, residing at the bottom of its ocean. Scientists are certain this is due to the intense gravitational pull of Saturn acting on Enceladus.

In the same way the Earth exerts a gravitational pull on the Moon to keep it in orbit, the Moon also exerts a gravitational pull on Earth. The gravitational pull of the Moon is what provides us with tides, and as Enceladus is much smaller than the Moon and Saturn is much more massive than Earth, Saturn's gravitational effect on Enceladus is much more dominant. The effect is actually so intense that Enceladus' interior is heated up through the friction of the continuous pulling and pushing on its interior due to Saturn's gravity. This effect is known as 'tidal heating' and it is the cause of the moon's interior hydrothermal vents and what stops the ocean turning into a frozen, barren world.

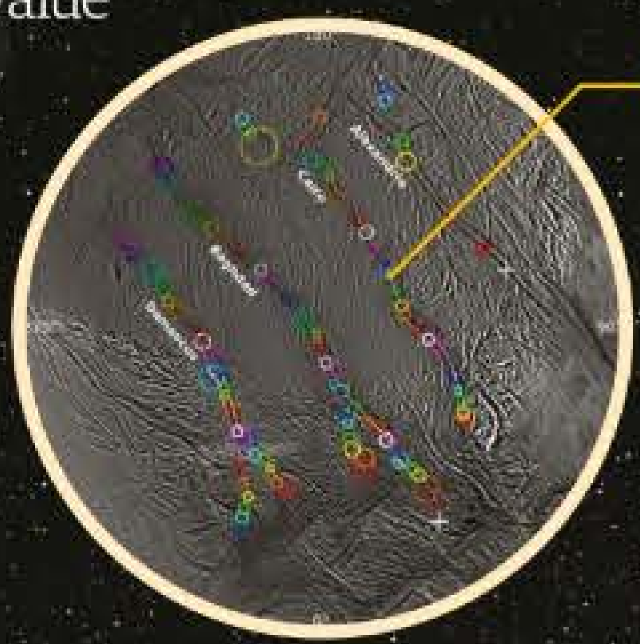
Now this new study has discovered another fascinating fact about Enceladus which has ramped up the excitement surrounding it, even after Cassini's demise in September 2017. A recent study led by Dr Frank Postberg of the University

Cassini completed 23 flybys of Enceladus and several deep dives into its plumes

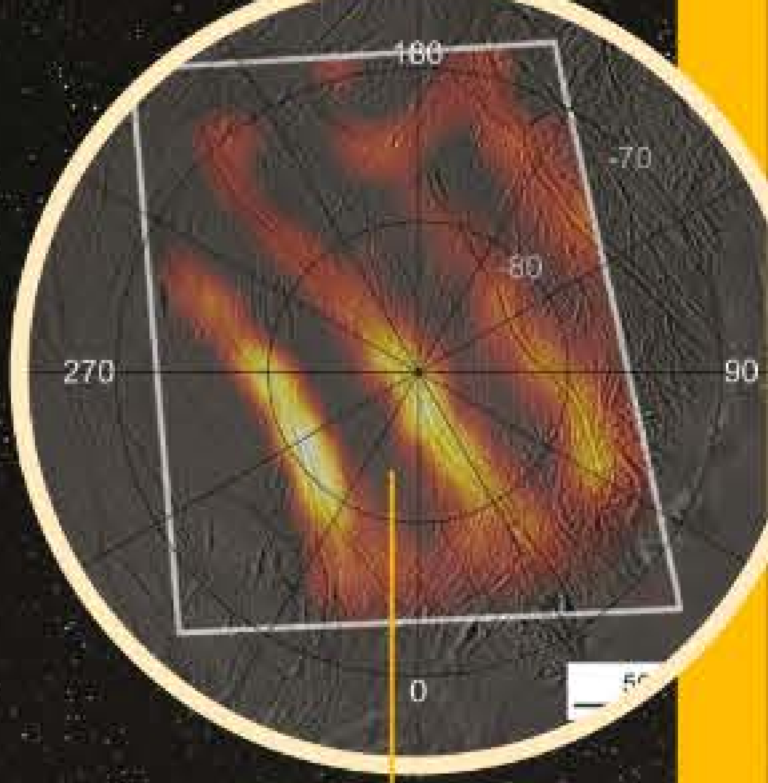
© NASA/JPL-Caltech; SwRI; Tobias Roetsch

What's happening at Enceladus?

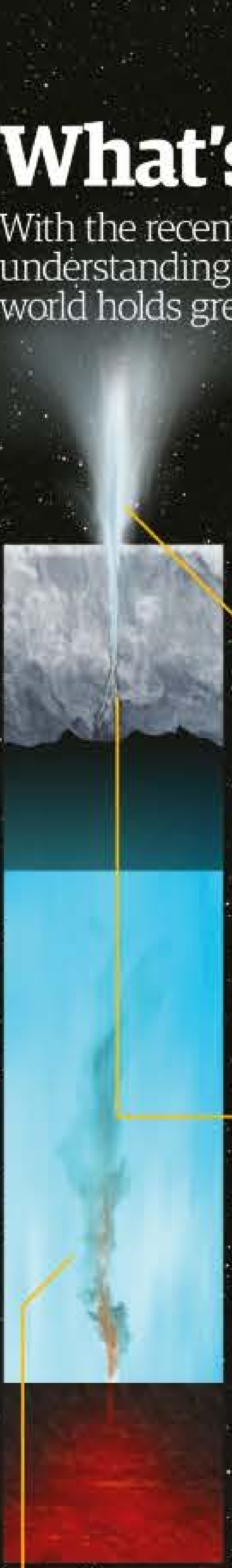
With the recent discovery of complex building blocks for life, understanding what Cassini learned about this small, icy world holds great value



100 geysers on Enceladus
This stereographic map plots the 100 geysers of water and ice shooting put of the moon's four main surface fissures from its south pole.



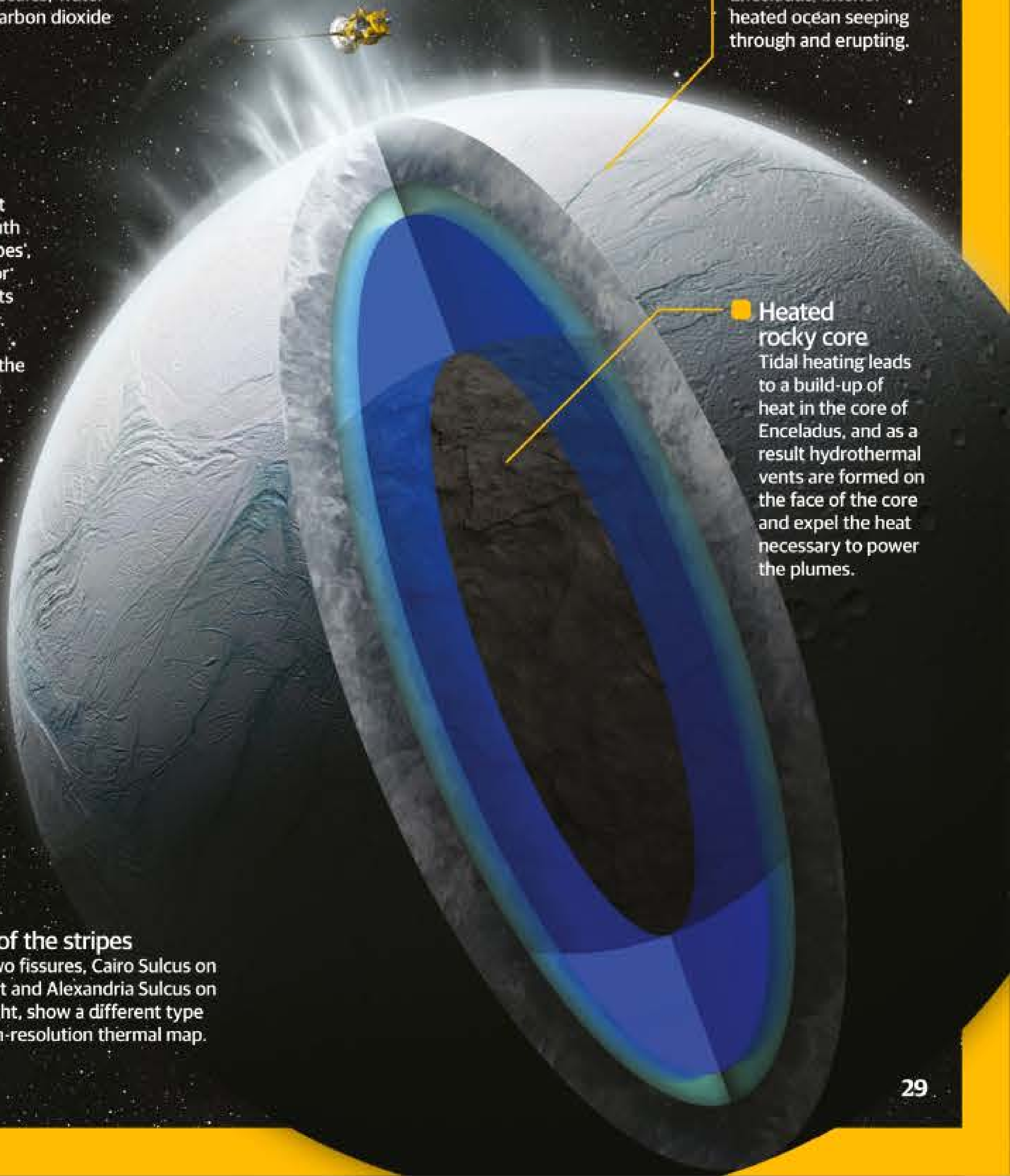
Heat mapping
This heat map of the south pole was taken using Cassini's Composite Infrared Spectrometer (CIRS). It shows the temperature drastically increases in the tiger stripes.



Geysers erupting
Cassini flew through these plumes at an altitude of roughly 200 kilometres (124 miles) to reveal they are made up of complex organic molecules, water vapour, volatile gases, carbon dioxide and carbon monoxide.

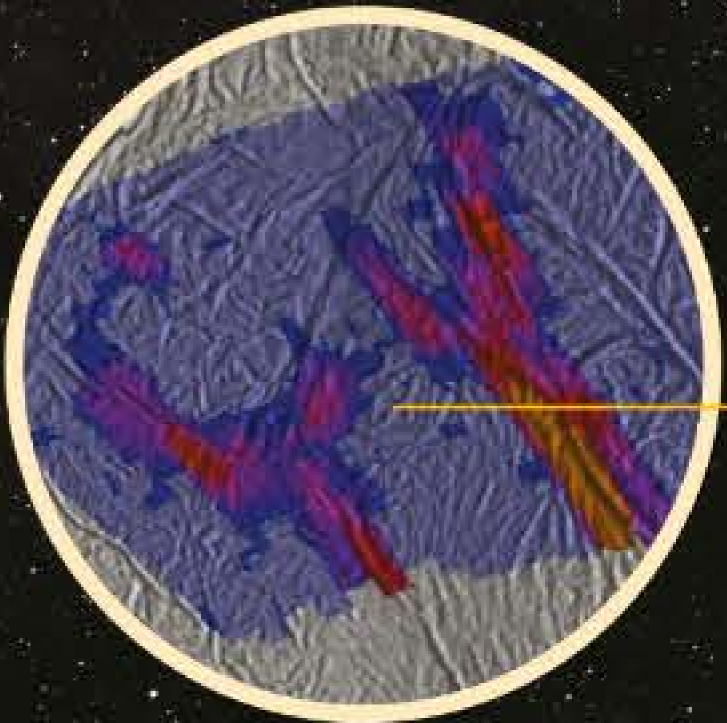
Fractures in the surface
The four prominent fractures in the south pole, the 'tiger stripes', provide the path for the interior contents and heat to escape. This is where the bubbles burst and the organic substances are released.

Subsurface ocean
This ocean is believed to to be ten kilometres (six miles) thick, and is believed to transport the organics on the walls of bubbles effervescing from the hydrothermal vents.

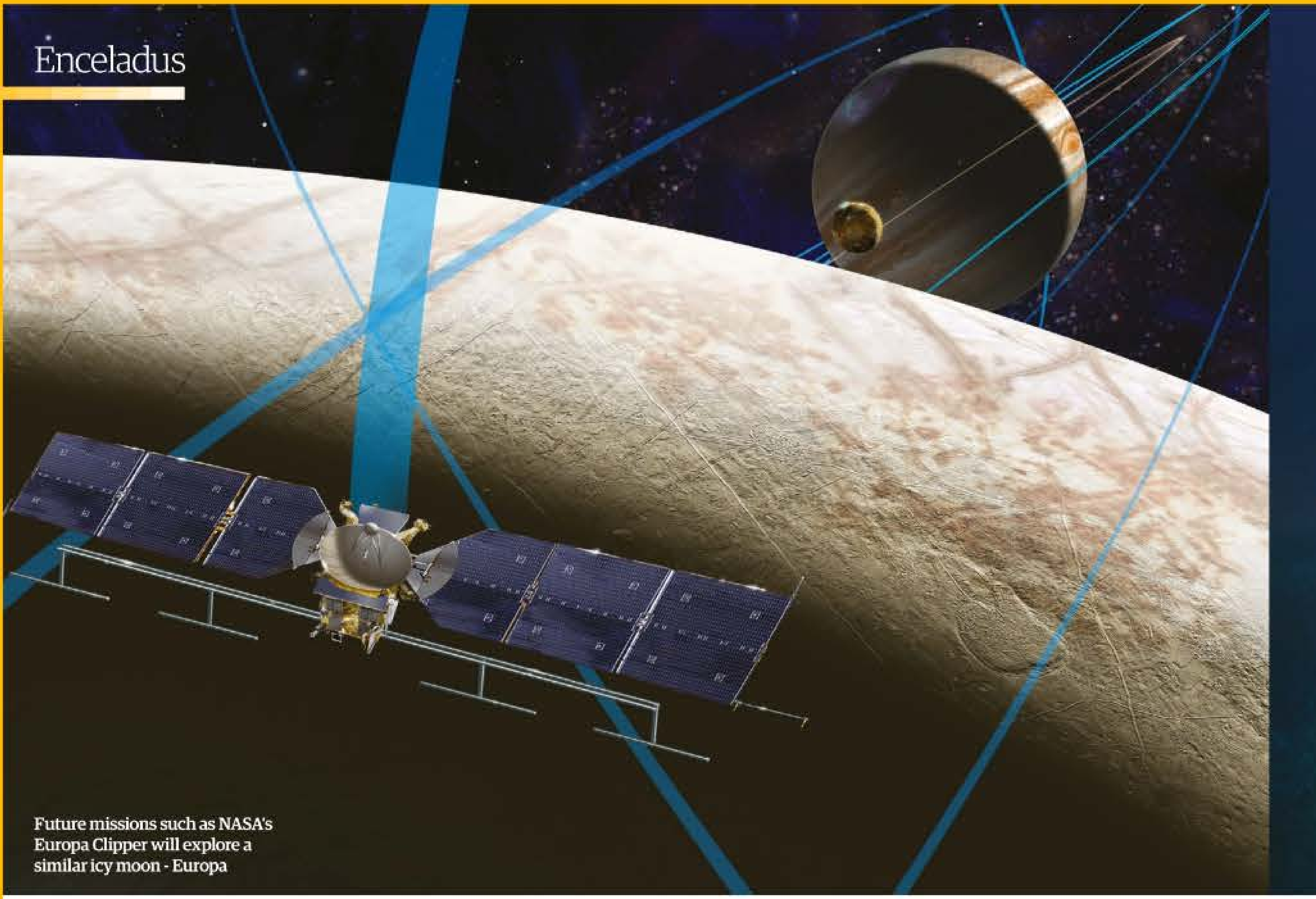


Tiger stripes
These blue stripes on the surface are the cracks made by Enceladus' interior-heated ocean seeping through and erupting.

Heated rocky core
Tidal heating leads to a build-up of heat in the core of Enceladus, and as a result hydrothermal vents are formed on the face of the core and expel the heat necessary to power the plumes.



Two of the stripes
The two fissures, Cairo Sulcus on the left and Alexandria Sulcus on the right, show a different type of high-resolution thermal map.



Future missions such as NASA's Europa Clipper will explore a similar icy moon - Europa

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> "Enceladus checks all the boxes for habitability: liquid water, organic material and a source of chemical energy" **Hunter Waite**

of Heidelberg, Germany, has identified incredibly complex organic molecules with masses over 200 atomic mass units, which is more than ten-times heavier than methane. "This is the first ever detection of such complex organics coming from an extraterrestrial water-world, but we do not know if the organics we found are of biogenic origin or in any way connected to life," explains Postberg. "Indeed, complex organics do not necessarily provide a life-friendly environment. On the other hand any life as we know it, and even any prebiotic chemistry, requires complex organic molecules."

This discovery comes as a result of two of Cassini's 12 on-board scientific instruments. The CDA and INMS are both mass spectrometers that were hit by ice grains at speeds of around 30,000 kilometres (18,641 miles) per hour. With each impact the ice grains were broken up and the instruments were able to take a look at the fragments that remained. "We can then analyse these fragments and compare them to related laboratory experiments to draw conclusions about the chemical nature of these organics. How the molecules break apart provides information on the elements present and the nature of the molecular structure," says Waite.

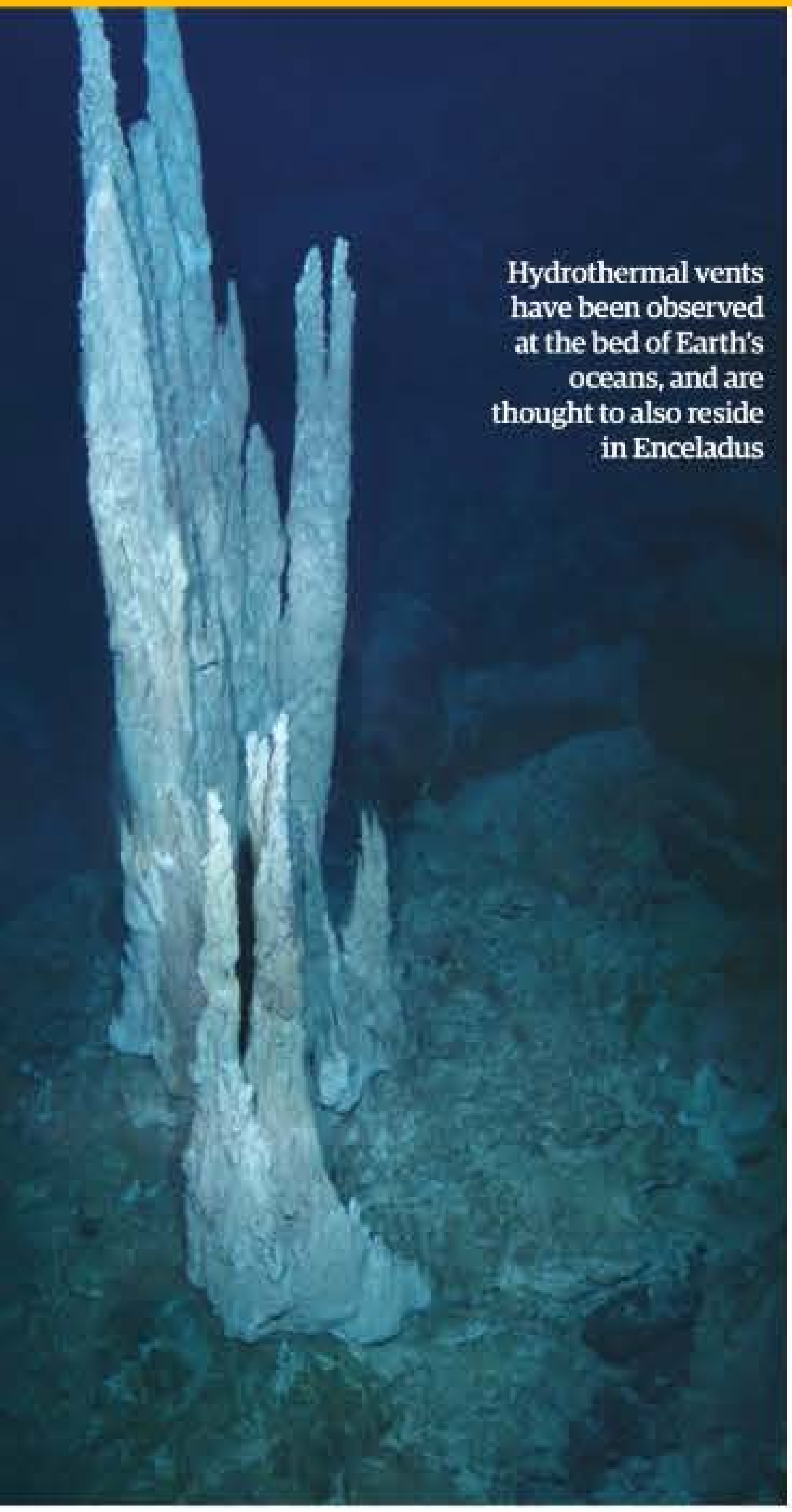
It seems like Enceladus is quite hydra-headed in terms of that when one question gets answered, three more enter in its place. Although scientists have been able to identify the complexity of molecules present at the distant water-world, now there are questions over how they are formed, what this tells us about the moon's potential habitability and if there are any forms of life residing there at this present time.

"In principle there is a wide range of possibilities [for how these molecules formed]. Such large molecules can only be created by complex chemical processes – including those related to life," explains Postberg. "Alternatively they could come from primordial material as found in some meteorites or, more likely, be generated by hydrothermal activity."

There are three main possible explanations as to how these carbon-rich molecules have come about, and all three are positive signs for life on Enceladus in their own way. One scenario is that these are primordial pieces of carbonaceous material that have been released due to the thermal evolution of the moon. The other is that these complex organics are the combination of simpler carbon materials that are formed on the aforementioned hydrothermal vents, or it is even possible that this is the refuse of living organisms. The first two abiotic scenarios are positive for a sign of life, as it means that there is a fuel source being created for any potential organisms. The last scenario, however, could mean that there is, or has previously been, a form of life at Enceladus. When asked about what type of life form could be at Enceladus, Waite replies that "life on Enceladus would likely be single-celled microbes, similar to the most primitive forms of life on Earth, such as methanogens."

In order to get to the bottom of how these organics turn up in such an environment, particularly as there is no spacecraft there at the moment, scientists require much more extensive theoretical models and laboratory experiments. How they're formed is relatively unknown, but how they find their way to the Cassini instruments is by hitching a ride on the surface of bubbles. "After entering the ocean the organics can be transported upwards to the ocean surface on the walls of rising bubbles of gas," says Postberg. "When reaching the ocean surface, the organics form a layer or film there."

However, even with all the questions that have surfaced courtesy of this detection of complex molecules, it has been more promising than Mars when it comes finding organic compounds. Postberg makes a point that "The most intriguing difference is how easily one finds complex organics on Enceladus compared to Mars. If you consider the enormous efforts put into the search for organics on Mars since the 1970s without success, it is just amazing how easily we found a complex and



Hydrothermal vents have been observed at the bed of Earth's oceans, and are thought to also reside in Enceladus

diverse organic chemistry on Enceladus just with a spacecraft flying by."

Mars has had numerous amounts of orbiters, landers and rovers searching for signs of life since the Mariner 9 became the first spacecraft to orbit Mars in 1971. The search for life on Mars is an idea that has been the driving force behind many Martian exploration missions, and scientists have since been finding evidence of ancient organic compounds. The most recent discovery is NASA's Curiosity rover drilling into a 3-billion-year-old sedimentary rock at the Gale Crater and finding 'tough' organic compounds. Curiosity's Sample Analysis at Mars (SAM) instrument found large, carbon-based, organic compounds that also include sulphur. Sulphur was not discovered at Enceladus, but this is because the instruments are not sensitive enough to detect sulphur. It could be the case that sulphur is present at Enceladus but it hasn't been detected, meaning the dry Red Planet and distant water-world moon could be very similar in terms of organic compounds. Mars is now considered an inhospitable world with no atmosphere, meaning that the Sun's unfiltered rays can rain down on the unprotected surface and evaporate any water. This makes it extremely hard for any form of life to survive in this difficult terrain. Now evidence has come to light of organic compounds at a more favourable environment, scientists will need to start looking at moons with interior oceans such as Enceladus, Europa, Ganymede and Callisto more extensively.

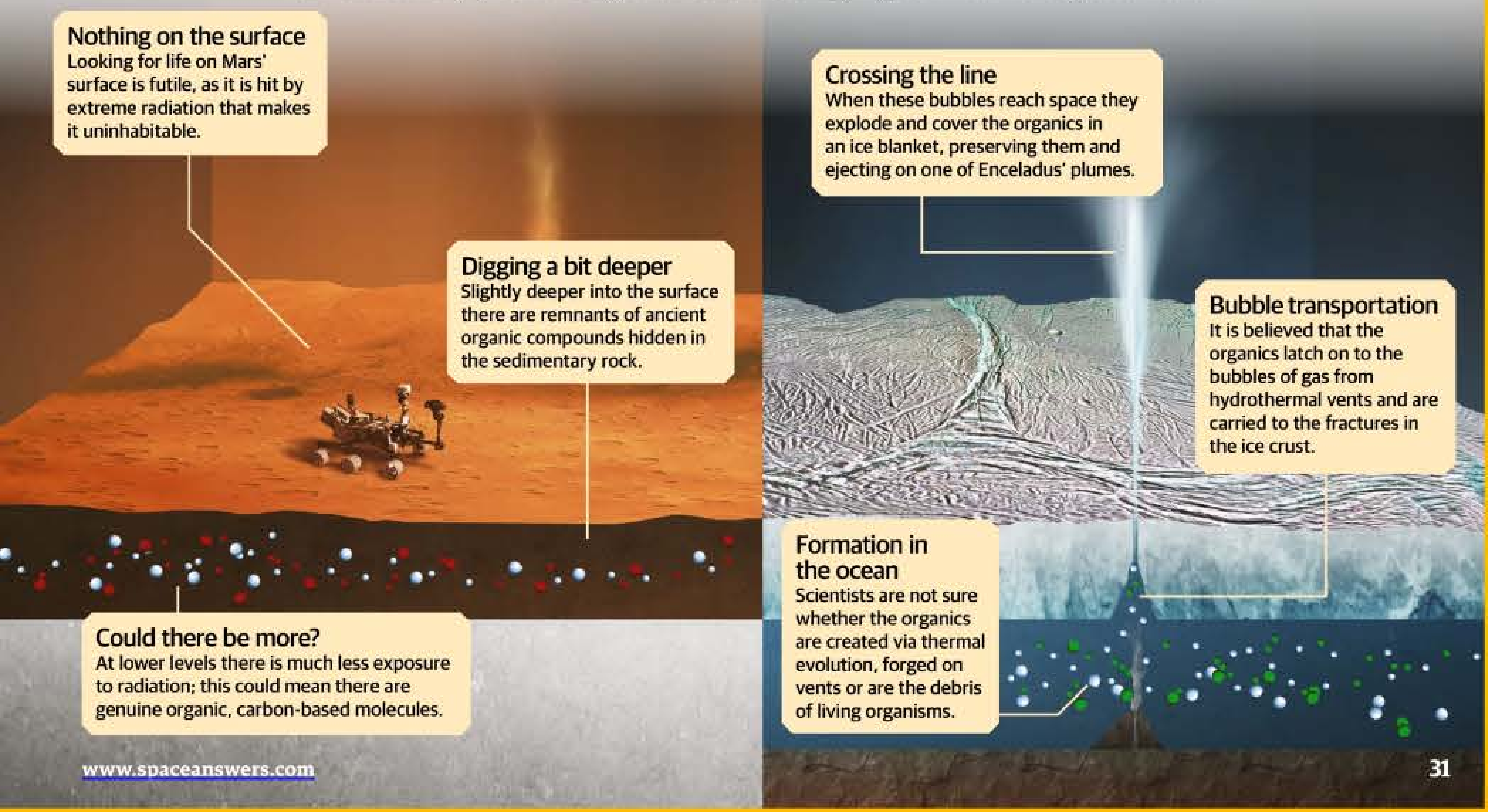
Unfortunately, the future exploration of Enceladus is looking bleak, as there is no spacecraft commissioned to go back to the Saturn system, and in particular Enceladus. When you reflect on the amazing discoveries that Cassini made with a collection of instruments that weren't designed for examining this unique world, as they were built before scientists knew about Enceladus' activity, imagine what astrobiologists and planetary scientists could learn from a spacecraft that was specifically made for studying the moon.

"There will probably be new Enceladus mission proposals for the next NASA New Frontiers call. A future Enceladus mission could consist of a series of flybys of Enceladus, similar to the Europa Clipper mission, or perhaps the spacecraft will go into orbit around Enceladus," says Spilker. "Any future Enceladus missions will probably carry instruments to search for evidence of life and to better characterise the habitability of the ocean."

With the advancements in technology and the innovative new techniques astronomers come up with each day, a pioneering orbiter - which could even include a lander to grace the surface - would unveil unbelievable results about Saturn's shining moon. It appears that the major space organisations such as NASA and the European Space Agency are convinced that Europa would be the better target, as it also exhibits signs of an interior ocean. However, with the data Cassini collected and the new discoveries that we continue to learn from it, a return to Enceladus is imminent.

Organics head-to-head: Mars vs Enceladus

Two different terrains have both exhibited signs of organic compounds, which is an extremely positive sign for scientists trying to find life beyond Earth



Nothing on the surface
Looking for life on Mars' surface is futile, as it is hit by extreme radiation that makes it uninhabitable.

Digging a bit deeper
Slightly deeper into the surface there are remnants of ancient organic compounds hidden in the sedimentary rock.

Could there be more?
At lower levels there is much less exposure to radiation; this could mean there are genuine organic, carbon-based molecules.

Crossing the line
When these bubbles reach space they explode and cover the organics in an ice blanket, preserving them and ejecting on one of Enceladus' plumes.

Bubble transportation
It is believed that the organics latch on to the bubbles of gas from hydrothermal vents and are carried to the fractures in the ice crust.

Formation in the ocean
Scientists are not sure whether the organics are created via thermal evolution, forged on vents or are the debris of living organisms.

Following his successful six-month Principia mission, Tim Peake is carrying out new duties for the European Space Agency (ESA) ahead of his next flight into space. We caught up with the UK astronaut at the European Astronaut Centre in Cologne to find out more

Written by Nick Spall

Behind the scenes ESA *with Tim Peake*

More than two years on from his launch to orbit aboard the Soyuz TMA-19M spacecraft from the Baikonur Cosmodrome in Kazakhstan, 45-year-old Tim Peake looks incredibly fit and well. He spent six months in microgravity, completing 2,720 or so orbits at around 27,000 kilometres (16,777 miles) per hour, 400 kilometres (248 miles) above the Earth on the International Space Station (ISS), yet he is now almost fully back to his pre-flight fitness and body strength, eager to be allocated his next mission assignment.

During this post-flight period, Tim found time to write and publish two books covering his space flight: *Hello, is this planet Earth?* as a compilation of the best of his own photos taken from orbit, plus the excellent *Ask an Astronaut*, which describes in great detail what it takes to be selected for astronaut training, and how it feels to experience the rigours and wonders of spaceflight. Tim's proceeds from both books are donated to The Prince's Trust charity, for which he is an ambassador.

Following some time in Houston for post-flight medical reviews and debriefing, Tim moved back to the European Astronaut Centre (EAC) with his family to take up the position of head of crew support, a post now called 'astronaut operations team lead'. In this role, he looks after all aspects of the ESA astronaut requirements during their missions on board the ISS.

> "I didn't ever feel the need to hang on to the station when outside, even though we keep one hand on the rails a lot of the time" **Tim Peake**

Tim's wife and two sons are back to daily life living in Cologne, Germany with him at home regularly again - this contrasts to his six months on the ISS when his children would occasionally wave to him on the ISS as it passed them serenely overhead. Communications with ISS crews is excellent, and families can access the astronauts on a daily basis by tele-link and emails.

The EAC itself is a large campus-style complex located close to the main airport at Cologne. It includes various ISS module simulators, a Soyuz capsule basic trainer, a deep-pool Neutral Buoyancy Facility for EVA training, fitness rooms and general training facilities, plus astronaut and support crew staff offices. Several UK trainers work at the EAC, including Matt Day, whose responsibilities include providing instructional videos for ESA astronauts. These can be uploaded to the ISS for specific operations tasks in orbit - for example, one covered Tim's telerobotic link-up and control from orbit of the Exomars rover test vehicle 'Bridget' located at the 'Mars-yard' at Stevenage during his 'Principia' mission.

The effects of weightlessness are now much better understood than during the early Salyut, Skylab and Mir precursor space station days. Muscle mass and strength, bone mineral density and visual acuity degradation are now expected and catered for, following on from the initial Space Adaptation Syndrome (SAS) feelings of nausea that afflict many astronauts early after their arrival on the ISS.

Tim explains: "When I first arrived at the Space Station I did go through the expected period of feeling a fullness in my head, with a stuffy nose and mild headaches. This went away after a few hours, though, and I adapted very well to weightlessness. I did initially lose about 5 kilograms from my 70 kilogram body weight - with a careful diet and strength exercise I was able to recover that."

More than 50 per cent of astronauts on long-duration missions have experienced a noticeable loss of visual acuity, becoming far-sighted. Some have had to rely on reading glasses while in space and after their return to Earth. This is thought to be due to intracranial pressure increases in 'zero-g' and its effect on the optic nerve. The detailed process behind this change is still being investigated on the ISS, and the UK's Dr Robert Marchbanks is leading one particular experiment for this condition. Tim's eyesight did change in space, but this, his bone density and muscle loss changes have almost fully returned to normal.

Tim explains: "On the ISS my eyesight changed so that I did use the reading glasses that we had on board as a back-up. Now my eyesight is only slightly less than it was before launch - and as a 45 year old that may well be a natural change anyway and completely unrelated to spaceflight... my father used reading glasses when he was 45, for example!"

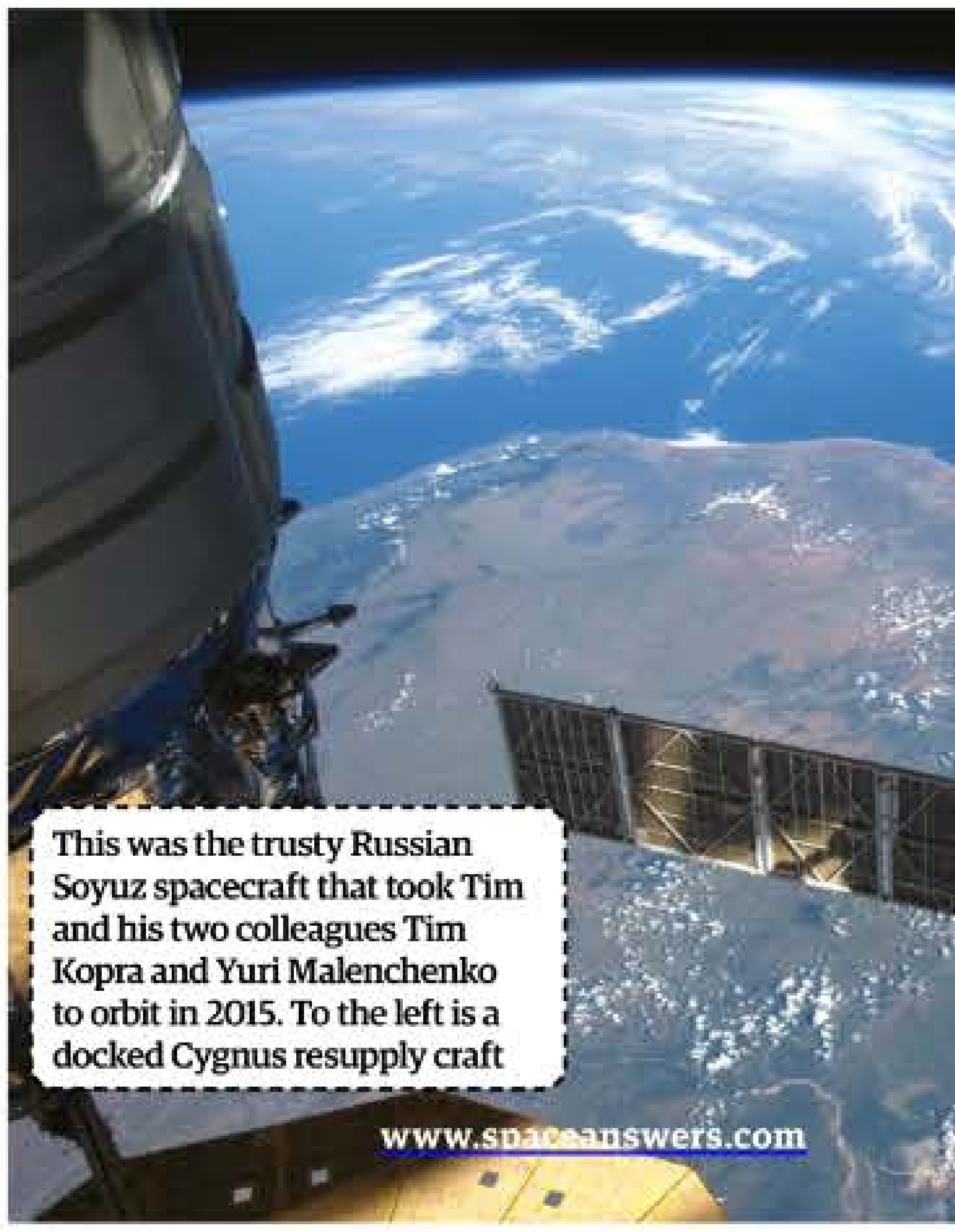
"All of the bone density loss I experienced - which was about two per cent overall - has now almost fully been restored, with my muscle strength fully back so that I am able to run long distances as much as I could pre-flight. The countermeasures we used on the ISS, including the ARED exercise machine, worked really well," he says.

As an experienced test pilot with over 3,000 hours of helicopter and fixed-wing flying, Tim could undertake the more dramatic aspects of spaceflight with ease. After, his nine-minute rocket ride into orbit, the difficult docking with the ISS that required spacecraft commander Yuri Malenchenko to use manual procedures at night, the four-hour 43-minute EVA spacewalk and the wild ride back on the Soyuz during re-entry were all exciting, but carefully trained for. Interestingly, it was the docking and berthing of the Dragon resupply freighter that Tim found most challenging:

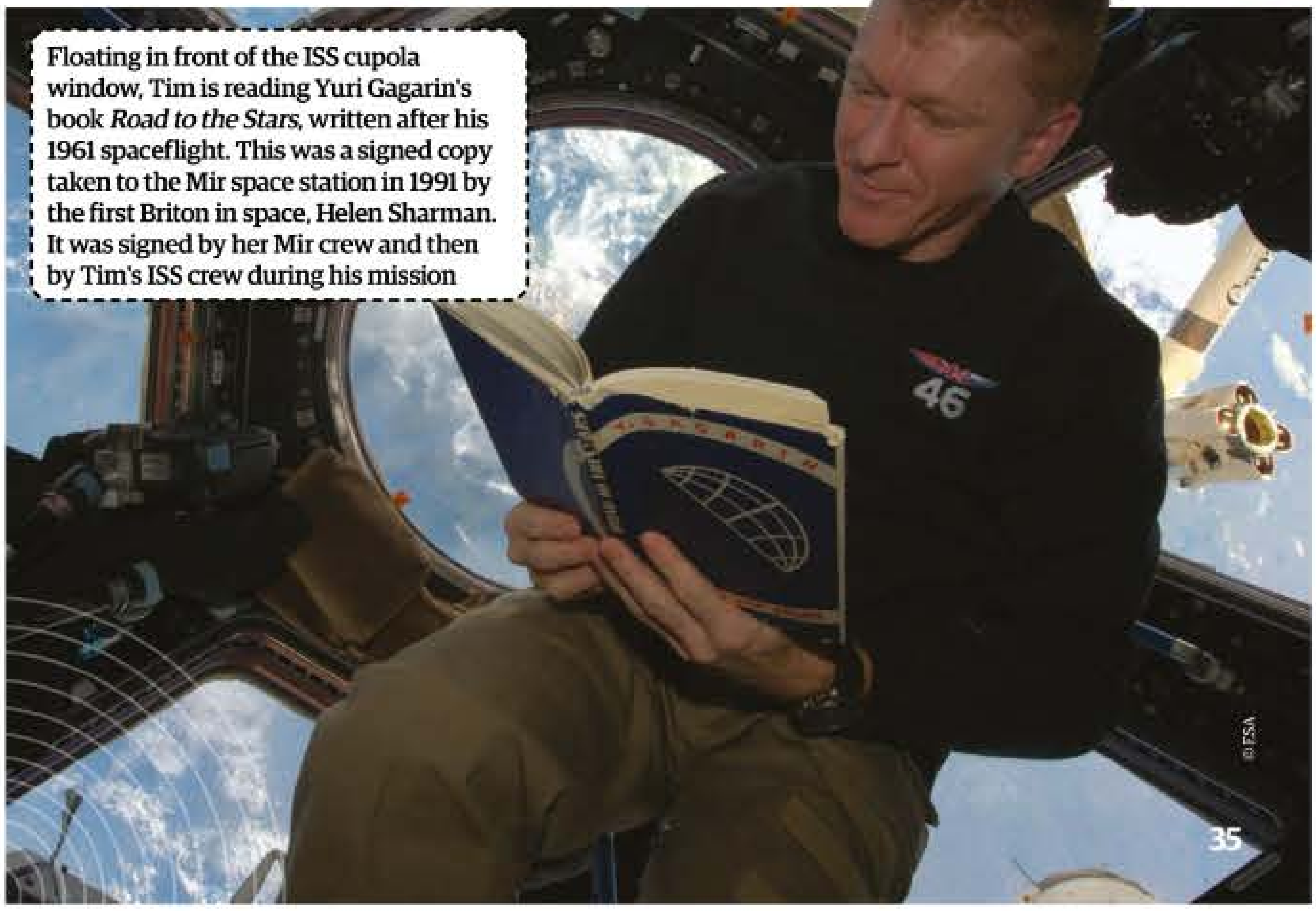
"Capturing and docking the Dragon required great concentration and care... a mistake that close to the hull of the ISS would have been very serious. However, I found the robot arm controls familiar after years of helicopter control experience, and all went well."

As to the EVA, how did he feel outside the ISS, tethered to the guide rails and floating 400

Here Tim is helping with the Novespace/Rêves de Gosse campaign, giving some lucky European children with disabilities the chance to experience the thrill of zero-g parabolic flight onboard a converted Airbus A310



This was the trusty Russian Soyuz spacecraft that took Tim and his two colleagues Tim Kopra and Yuri Malenchenko to orbit in 2015. To the left is a docked Cygnus resupply craft



Floating in front of the ISS cupola window, Tim is reading Yuri Gagarin's book *Road to the Stars*, written after his 1961 spaceflight. This was a signed copy taken to the Mir space station in 1991 by the first Briton in space, Helen Sharman. It was signed by her Mir crew and then by Tim's ISS crew during his mission

©ESA

What Tim Peake did during Principia

Airway Monitoring

Studying the effects of dust particles and other detritus on the human respiratory system in a weightless environment.

Brain-DTI

Testing and understanding how an astronaut's brain reacts and functions when processing information and commands while they are weightless in the microgravity environment of space.

Circadian rhythms

Testing the levels of melatonin in the body and seeing how a drastically different day-night cycles affects Peake's sleep patterns.

Space headaches

Living in a highly pressurised chamber can cause serious headaches, so Peake and the crew will have to fill out questionnaires to determine the severity and cause of these space headaches.

Muscle biopsy

This study will determine the effect that being weightless for six months has on Peake's muscles, both before and after his time onboard the ISS.

Energy levels

Peake and the rest of the crew onboard the ISS will provide the ESA and NASA with data on how many calories an astronaut needs to function to the required standard.

Cartilage and osteoporosis

Peake will be closely monitored to see how the reduction of cartilage affects his bone density and the potential development of osteoporosis while weightless.

Skin degradation

The first ever space-based experiment focused on skin monitored the faster rate at which astronauts shed skin cells and examine the biological processes behind this.

Plasma

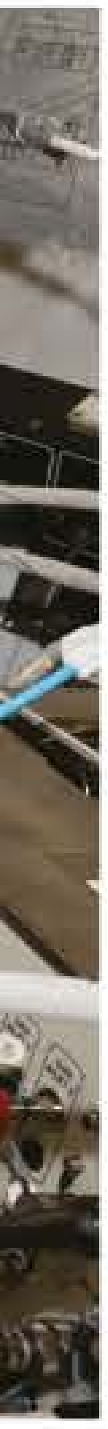
Creating an ionised gas known as plasma in space allows dust particles to behave more realistically than they would on the Earth. The aim is to understand atom interactions.

Blood cell function

To test the effects of bone marrow fat changes in a weightless environment, bone marrow was exposed to radiation and the results were monitored.

One of Tim's responsibilities included research with the Airway Monitoring experiment. This measured nitric oxide in exhaled air and is part of a study that may assist asthma sufferers one day

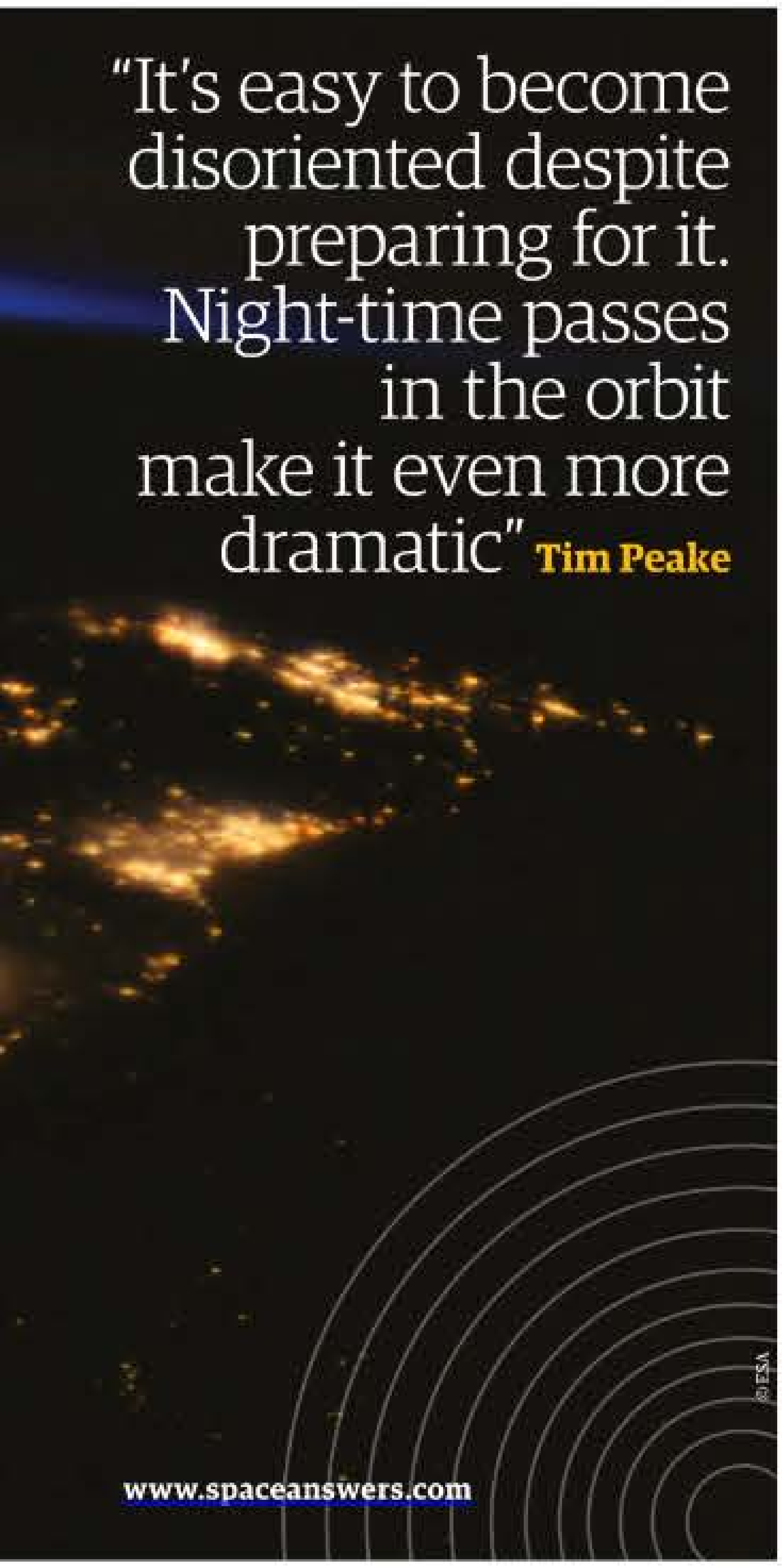
Tim's photo of the UK at night, 400km below. In orbit he experienced 16 night-time passes of the Earth every day. Below, his family, plus many others, often waved back as he went overhead!



kilometres (248.5 miles) above the Earth? "It is similar to our training in the buoyancy tank, and the safety tethers that you use give a feeling of security," he explains. "However, being 'upside-down' beside the lab modules, then reversing the position occasionally as part of the process of laying cables along the hull did require lots of focus, as it is a strange feeling. It's easy to become disoriented despite expecting and preparing for it. Night-time passes in the orbit make it even more dramatic. I didn't ever feel the need to hang on to the station when outside, even though we keep one hand on the rails a lot of the time."

Tim's hard work on the microgravity science research and outreach tasks of Principia as part of the ISS Expedition 46/47 has earned him widespread respect from both the national press and scientific community. He was involved in over 250 on-going ISS experiments, with over 30 closely covered during the Principia mission.

Some Tim found highly rewarding: "My probable favourite was ESA's Airway Monitoring experiment, which was challenging to execute using the space station airlock as a hypobaric chamber, and will benefit asthma sufferers here on Earth. The protein crystal growth experiment was one I would like to undertake again. It has the potential for huge benefits in drug development, and there is UK involvement in analysing the crystal structures after they return to Earth. This also applies to the Electro-Magnetic Levitator, where companies such as Rolls Royce in the UK are interested in its application for alloy turbine blade studies. As an ESA astronaut, I was closely responsible for running the Columbus research module in addition to being a specialist for the Japanese Space Agency's 'Kibo' laboratory. We do spend a lot of each intensive day on our own with lots of tasks, and often don't get to chat much - the interior volume of the ISS is about the same as a 747!"



"It's easy to become disoriented despite preparing for it. Night-time passes in the orbit make it even more dramatic" **Tim Peake**

© ESA

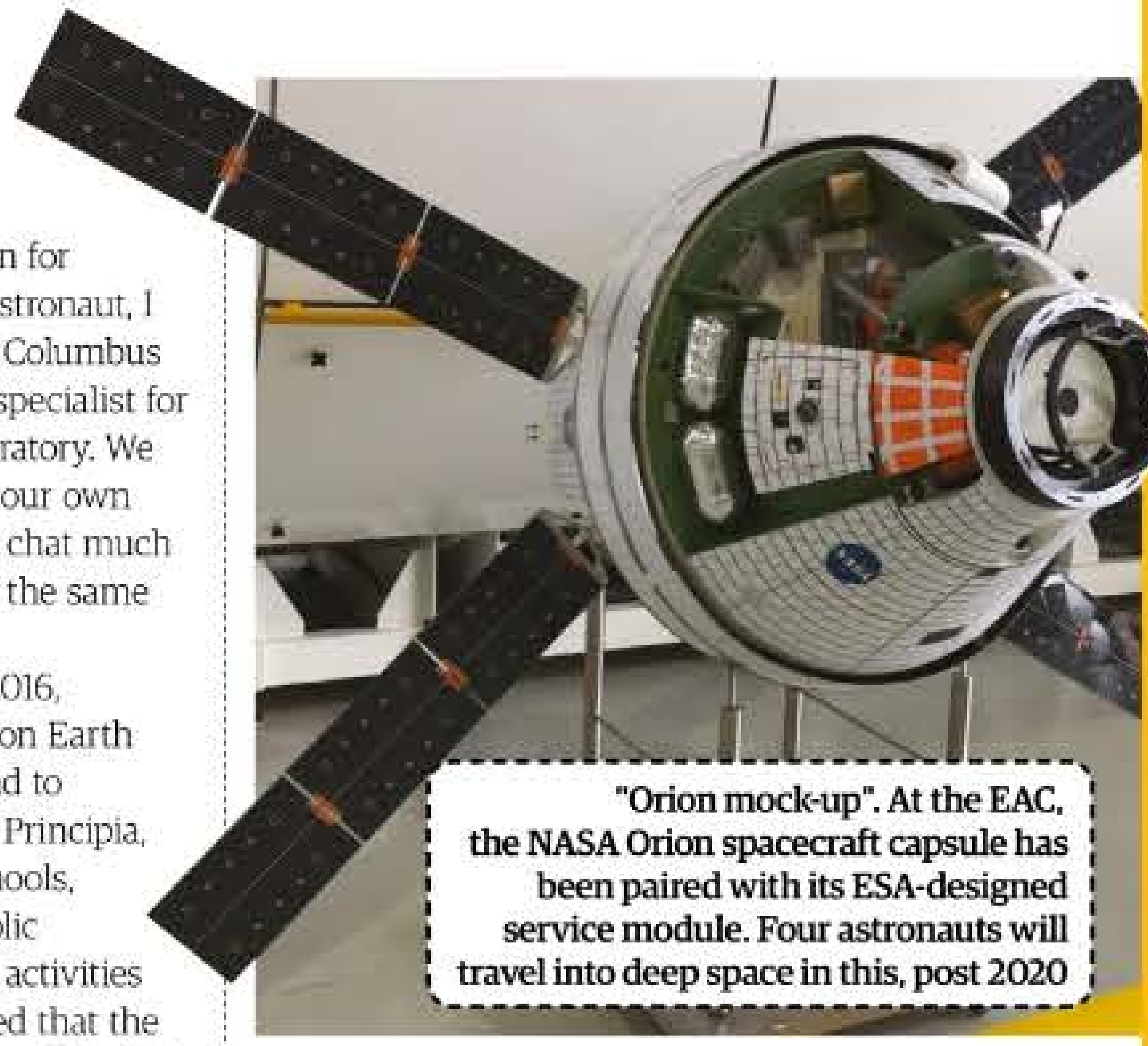
Since his return from space in June 2016, Tim has not only had to readjust to life on Earth physically and mentally, but has also had to continue the public outreach aspects of Principia, carrying on with post-flight visits to schools, colleges and institutions and giving public lectures as part of his STEM inspiration activities for young people. "It is generally accepted that the intensity of the public outreach work from Principia will be a hard one to follow for future missions!", he says. "Thanks to the great organisation and hard work of the UK Space Agency and ESA teams, we involved up to 1.6 million school children in over 30 projects, with 10,000 schools signing up and following the ISS activities."

Tim is currently awaiting his next spaceflight assignment. As an ESA astronaut from the intake group of six in 2009, he will be joining a new 'second flight' sequence to the ISS - all of the new astronauts have experienced missions to the space station, with only the relatively recently appointed German astronaut, Matthias Maurer, yet to make his first spaceflight.

In January 2017, ESA's director general Jan Wörner confirmed that Tim was due for a second mission to the ISS. The UK is the fourth-largest contributor to ESA and that, plus its recent involvement in human-spaceflight experiments on the ISS, will mean that Tim appears firmly in the line-up for the chance at a second flight. However, this assignment will take several years to realise. The current rate of one or two ESA astronaut visits to the Station per year, plus the need for a two-and-a-half-year specific training sequence post the actual mission assignment will mean that as of January 2018, it will most likely be several years before Tim could join the ISS standard complement of six crew members in orbit.

"At present, ESA's Paolo Nespoli is on board for his 'Vita' mission, with Alexander Gerst assigned to a 2018 flight, followed by Luca Parmitano in 2019. The ESA 2019 Ministerial meeting will consider future ISS commitments, most likely confirming missions to the ISS to 2024 and beyond. Therefore, the realistic earliest date for my next mission would be at least mid-2020," Tim tells us.

In recent years, post-retirement of the US Space Shuttle programme in 2011, ESA and NASA astronauts have had to fly to orbit aboard the venerable three-seater Soyuz capsules that have been operating for over 40 years. Soon though, the US will be bringing forward two new spacecraft to access the ISS via commercial agreements: the SpaceX 'Dragon V2' spacecraft with its Falcon 9 Block 5 launcher, and the Boeing CST-100 Starliner capsule that will be carried to orbit by an Atlas V rocket. These seven-seater spacecraft will be the mainstay of ISS operations through to beyond 2024 for low-Earth orbit access, and are due to begin crewed test flights in 2018.



"Orion mock-up". At the EAC, the NASA Orion spacecraft capsule has been paired with its ESA-designed service module. Four astronauts will travel into deep space in this, post 2020

Tim says: "It is likely that ESA astronauts will join the two US spacecraft for accessing the ISS via NASA barter agreements. This implies that I could one day take a seat in one of the US vehicles, rather than in the left- or right-hand seats of the Soyuz as previously occurred during my Principia mission."

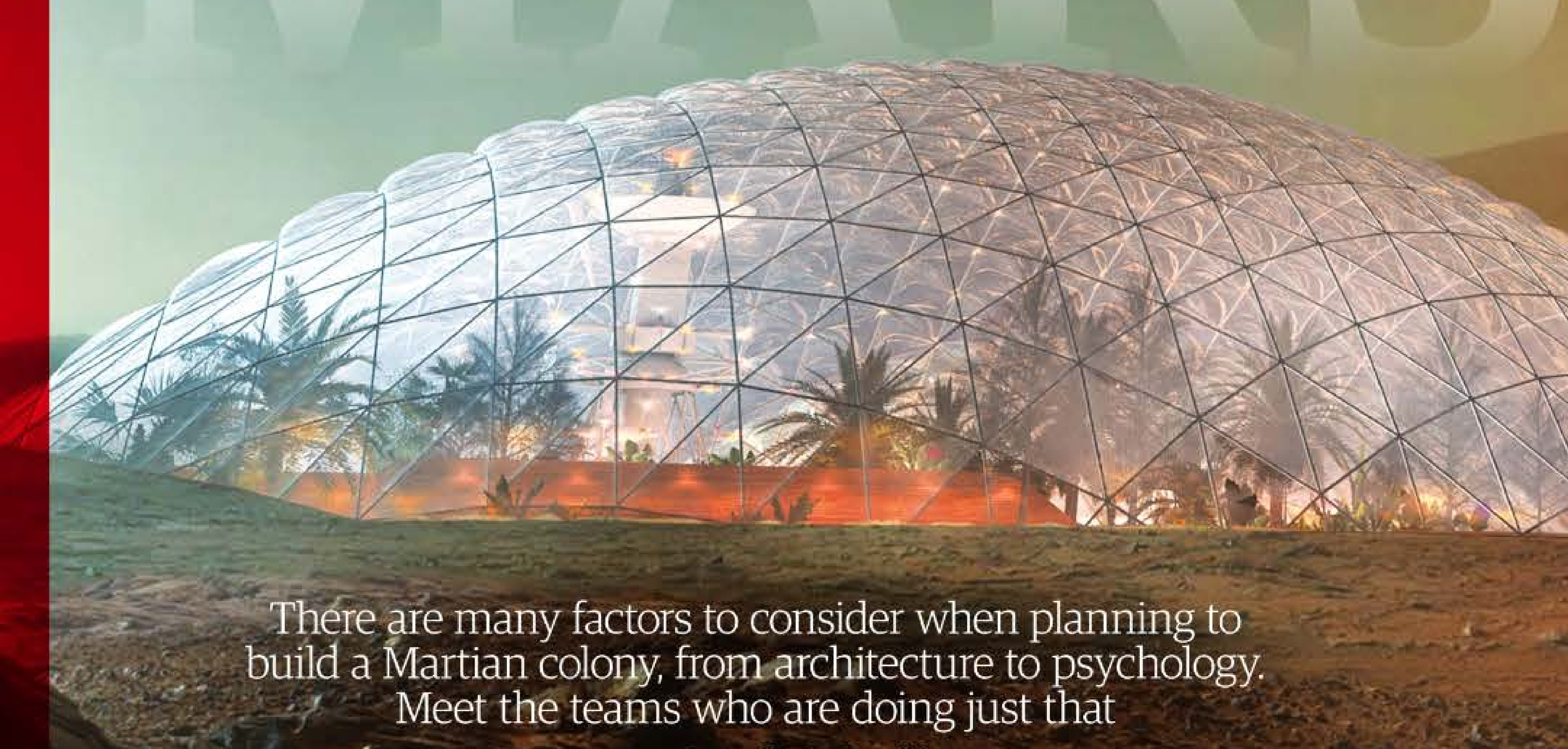
ESA is currently committed to providing the service modules for the new four-seat Orion deep-space vehicles, which aims to one day take astronauts to Mars. Other current ESA plans are to take part in the Deep Space Gateway (DSG) operations, helping to crew the proposed modular station that will orbit the Moon in cislunar space. This will allow for a NASA-led international return to the Moon itself, with the possibility of then extending their reach to Mars.

Tim is now 45 years old, but astronauts can continue through their mid-50s and beyond - Paolo Nespoli, for example, is now 60 years old. This means that Tim could join ESA human-spaceflight missions possibly up to the early 2030s. By that time, joint international projects may mean that he will even be part of future lunar exploration, with the 'Moon Village' concept being a particular favourite of ESA's as part of its commitment to explore the Solar System.

ESA is also increasing its cooperation with China's National Space Administration, following a 2015 agreement to boost collaboration. In August 2017, astronauts Samantha Cristoforetti and Matthias Maurer joined 16 Chinese astronauts for nine days of joint sea-survival training off China's coastline. As a successor to its experimental predecessors Tiangong 1 and 2, China is planning a new larger modular station for launch and assembly post 2020.

For Tim Peake, assuming the UK government continues to support ESA, the prospects of future flights - and possibly for new UK astronauts - to the ISS, perhaps the emerging Chinese station or even to the DSG lunar orbit outpost, certainly look good.

WOULD YOU MARS



There are many factors to consider when planning to build a Martian colony, from architecture to psychology. Meet the teams who are doing just that

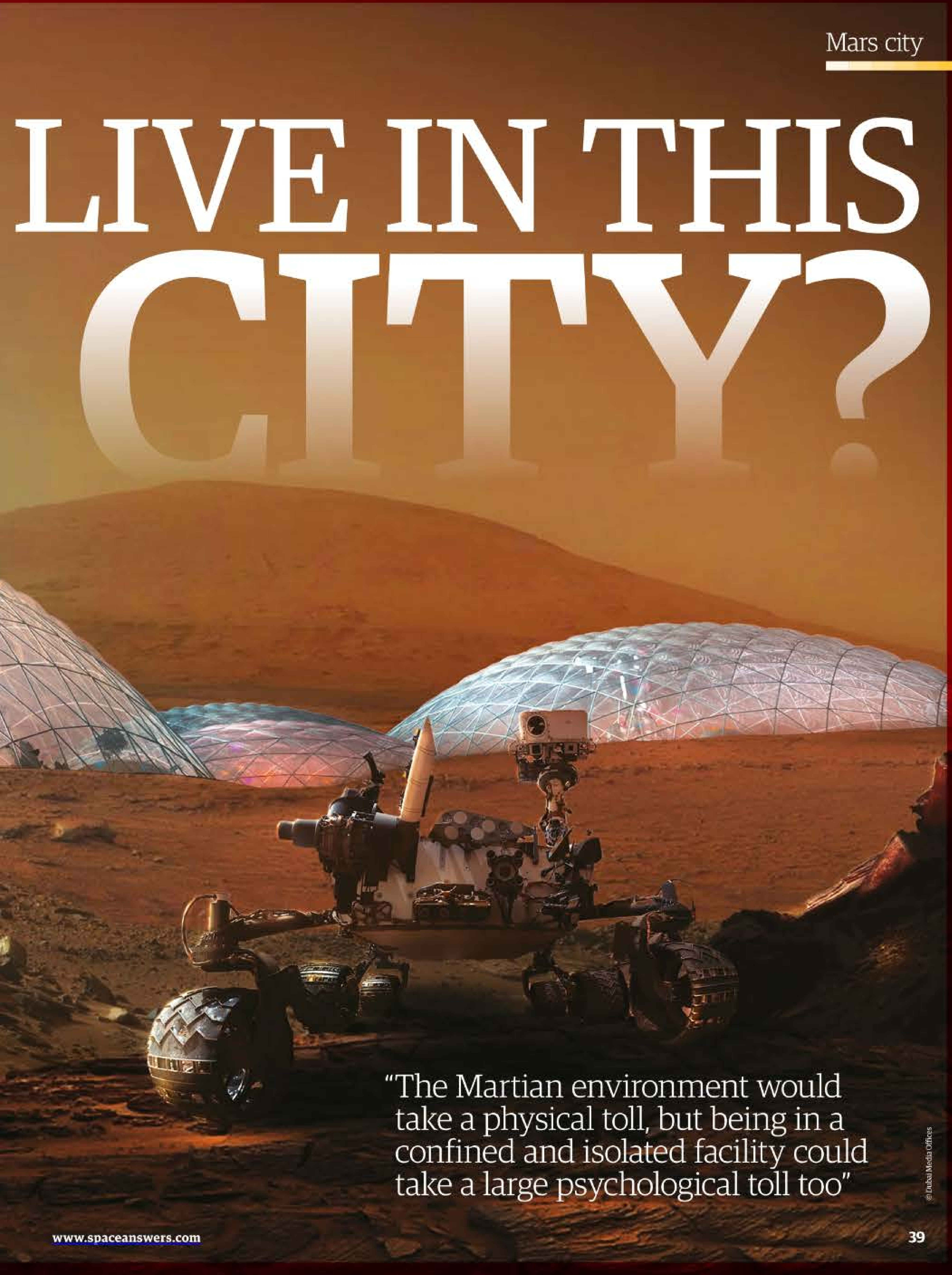
Reported by Lee Cavendish

Humans thrive on exploration, and while our race has explored virtually everything there is to offer on Earth, the urge to go further persists. This is why billions of people across the globe wish to break the boundaries of Earth and explore our neighbouring planet, Mars. Big names such as NASA, SpaceX and Virgin Galactic are all making huge steps in getting humans into space in a spacecraft that is capable of making the minimum 54.6-million-kilometre (33.9-million-mile) voyage. But what is to happen to the group of pioneers once they actually arrive?

With over two decades of close surveillance of Mars, courtesy of an array of orbiters, landers and rovers, scientists now know that the surface of Mars is a dry, cold and cruel environment for humans. If humans were to survive on Mars they would have to be protected in a confined sanctuary. The Martian environment would take a physical toll on its inhabitants due to its less intense gravity and sunlight, but being in a confined and isolated facility could take a large psychological toll too.

Given that the success of a mission can be affected by the physical and psychological health of its crew members, space agencies are getting increasingly creative in their approach – without leaving Earth. One such experiment – Mars-500 – was run by the Russian Institute for Biomedical Problems and the European Space Agency. The experiments were conducted between 2007 and 2011 in Moscow, Russia. Its aim was to understand the effects of future manned missions on man by isolating six people in a 'spacecraft' for 520 days, as if they were making the return journey to Mars.

LIVE IN THIS CITY?



"The Martian environment would take a physical toll, but being in a confined and isolated facility could take a large psychological toll too"

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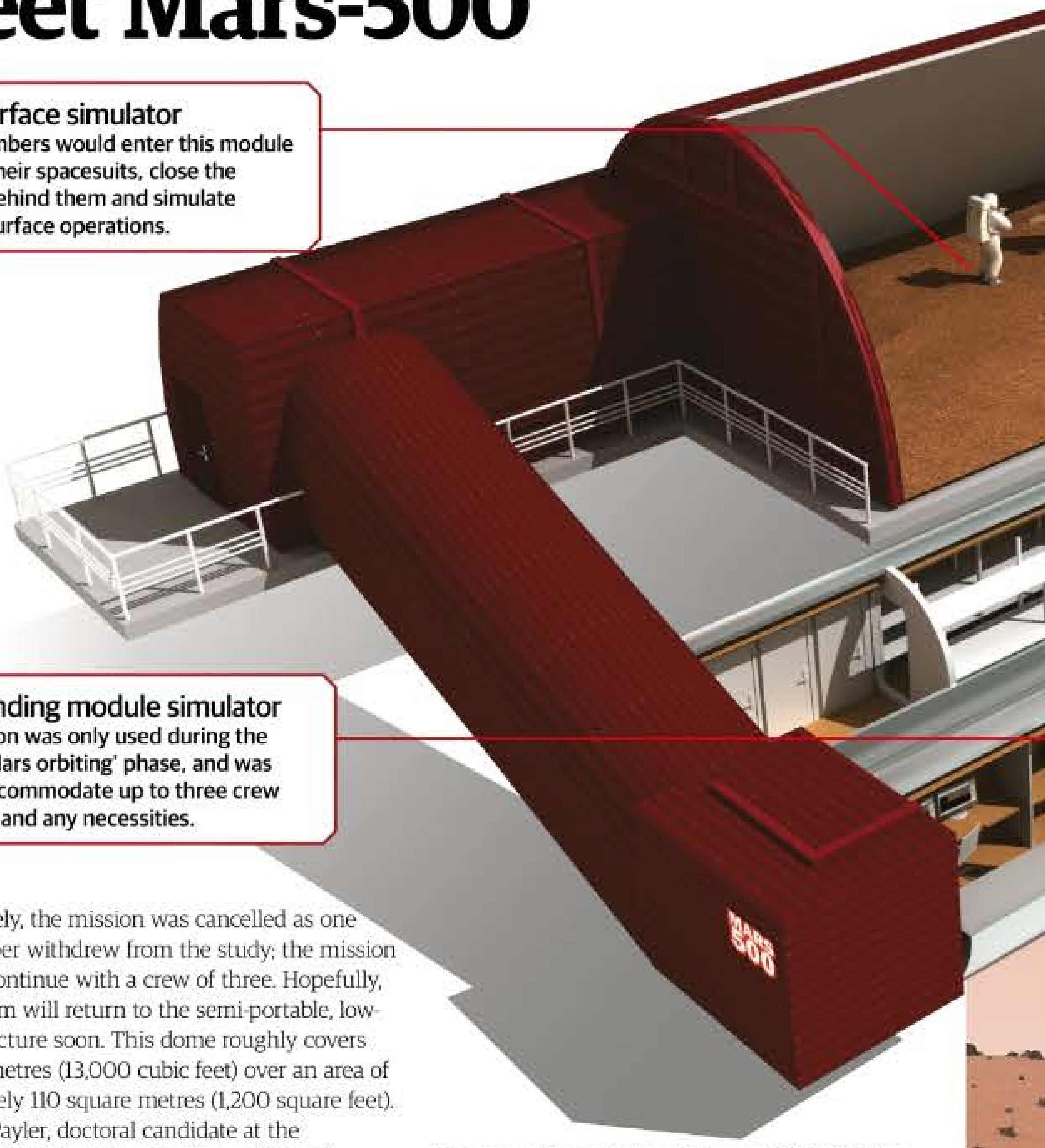
The Mars-500 crew spent 520 days isolated in a facility located in Moscow, Russia

Meet Mars-500



Mars surface simulator
Crew members would enter this module wearing their spacesuits, close the 'airlock' behind them and simulate Martian surface operations.

Mars landing module simulator
This section was only used during the 30-day 'Mars orbiting' phase, and was able to accommodate up to three crew members and any necessities.

The study was divided into three stages: firstly, a short 14-day simulation in order to test the facilities and operational procedures, followed by a 105-day isolation study undertaken with six crew members of Russian and European origin. In the final stage, six international crew members participated in a full 520-day isolation study, which included a simulated Mars landing and three 'Mars-walks'.

The purpose of this experiment was to gain valuable information about the psychological and physiological changes that may occur in participants during a long-term mission to Mars. The experiments yielded very interesting results regarding the crew members' activity and sleep levels. It was found that as the days wore on, the crew were more interested in their beds! In fact, on the 'return journey' to Earth, the crew spent nearly 700 hours longer in bed than the 'journey to Mars'. It was only in the last 20 days that the crew perked up, before 'returning' to Earth on 4 November 2011.

Less than 18 months after the end of Mars-500, a new simulation research project, the Hawaii Space Exploration Analog and Simulation (HI-SEAS), led by the University of Hawaii at Mānoa, and funded by NASA commenced. The HI-SEAS habitat is located some 2,500 metres (8,200 feet) above sea-level, atop the Mauna Loa volcano in Hawaii; it is the closest Mars-like environment we have on Earth. Its dry and almost lifeless scenery resembles Mars and, when combined with the HI-SEAS crews' delayed communications, partial self-sufficiency and enclosed habitat, makes a prime experiment for identifying the factors required for a successful long-duration planetary surface mission.

There have been five missions completed so far, and a sixth had begun in February 2018.

Unfortunately, the mission was cancelled as one crew member withdrew from the study; the mission could not continue with a crew of three. Hopefully, another team will return to the semi-portable, low-impact structure soon. This dome roughly covers 370 cubic metres (13,000 cubic feet) over an area of approximately 110 square metres (1,200 square feet).

Samuel Payler, doctoral candidate at the University of Edinburgh and science officer of HI-SEAS mission V, explains to **All About Space** the aims of the mission: "The goal of HI-SEAS is to understand what you have to go for in the crew composition to ensure the crew cooperate. You have to ask questions like: how do you pick your team of astronauts? What [characteristics] do you look for in them? What will picking certain things result in?

The Mars 500 crew kept up with regular training throughout the duration of the mission

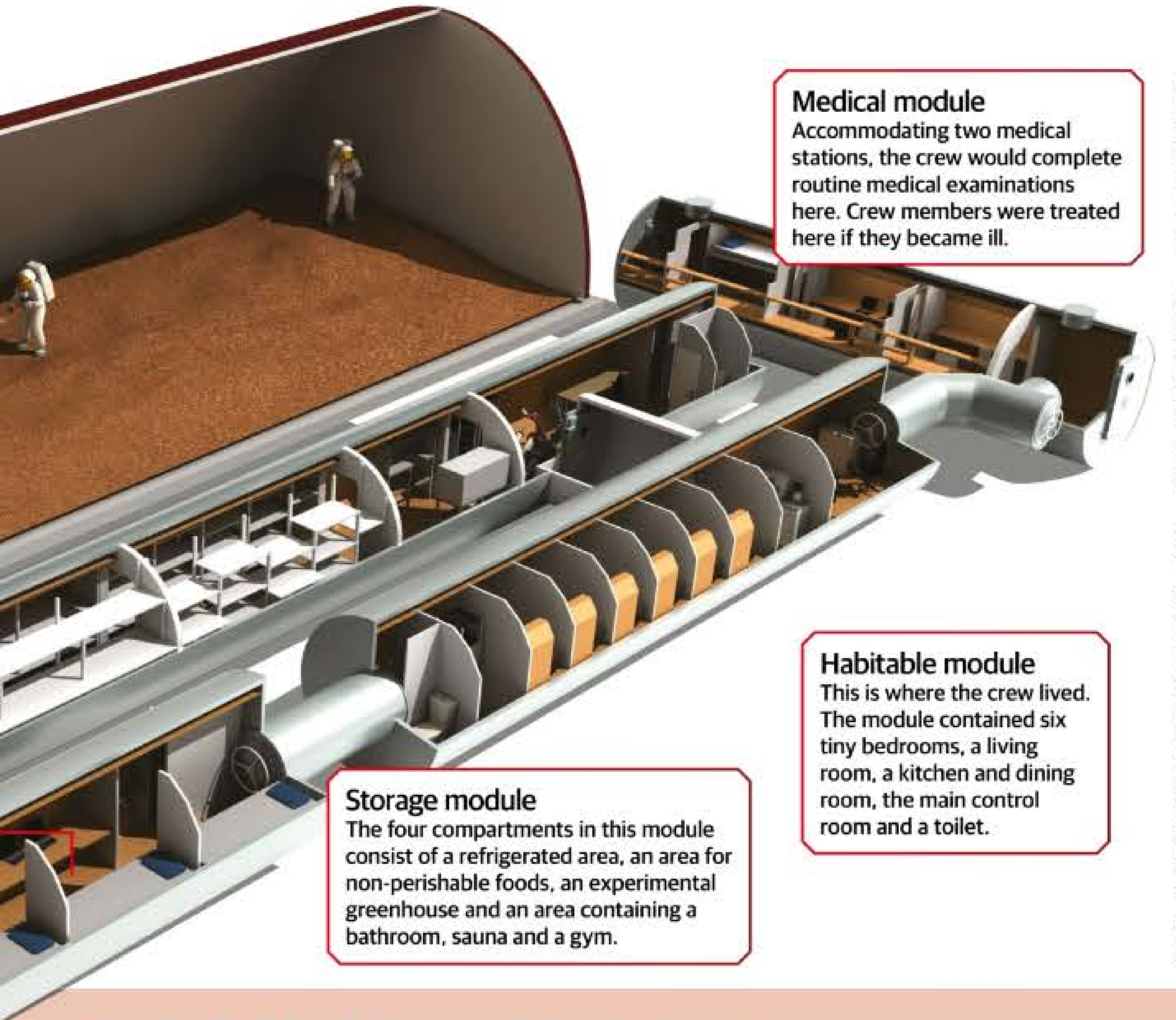
"This is intended to produce the most cohesive and productive team together for Mars, especially when you spend billions and billions of pounds on getting there. You don't want the team to fight and not be productive."

Looking toward the future, the United Arab Emirates (UAE) announced plans to build the largest ever space-simulation city just last year. The £100 million ($140 million) project, dubbed the Mars Science City, will cover a humongous 177,000 square metres (1.9 million square feet) in the Emirati desert in Dubai. To put that into perspective, that is over 1,600-times larger than the HI-SEAS habitat. This incredible structure comes as part of the UAE's 'Mars 2117 Strategy', aiming to build the first settlement on Mars in the next 100 years.

The uniqueness of the Mars Science City cannot be understated; the innovative advantages of this structure are like nothing ever seen before, and it will be vital to how we build a settlement on Mars. This building will harness its environment by using

This city will be the largest space-simulation city ever built

© ESA; Dubai Media Offices; Adrian Mann



Medical module
Accommodating two medical stations, the crew would complete routine medical examinations here. Crew members were treated here if they became ill.

Habitable module
This is where the crew lived. The module contained six tiny bedrooms, a living room, a kitchen and dining room, the main control room and a toilet.

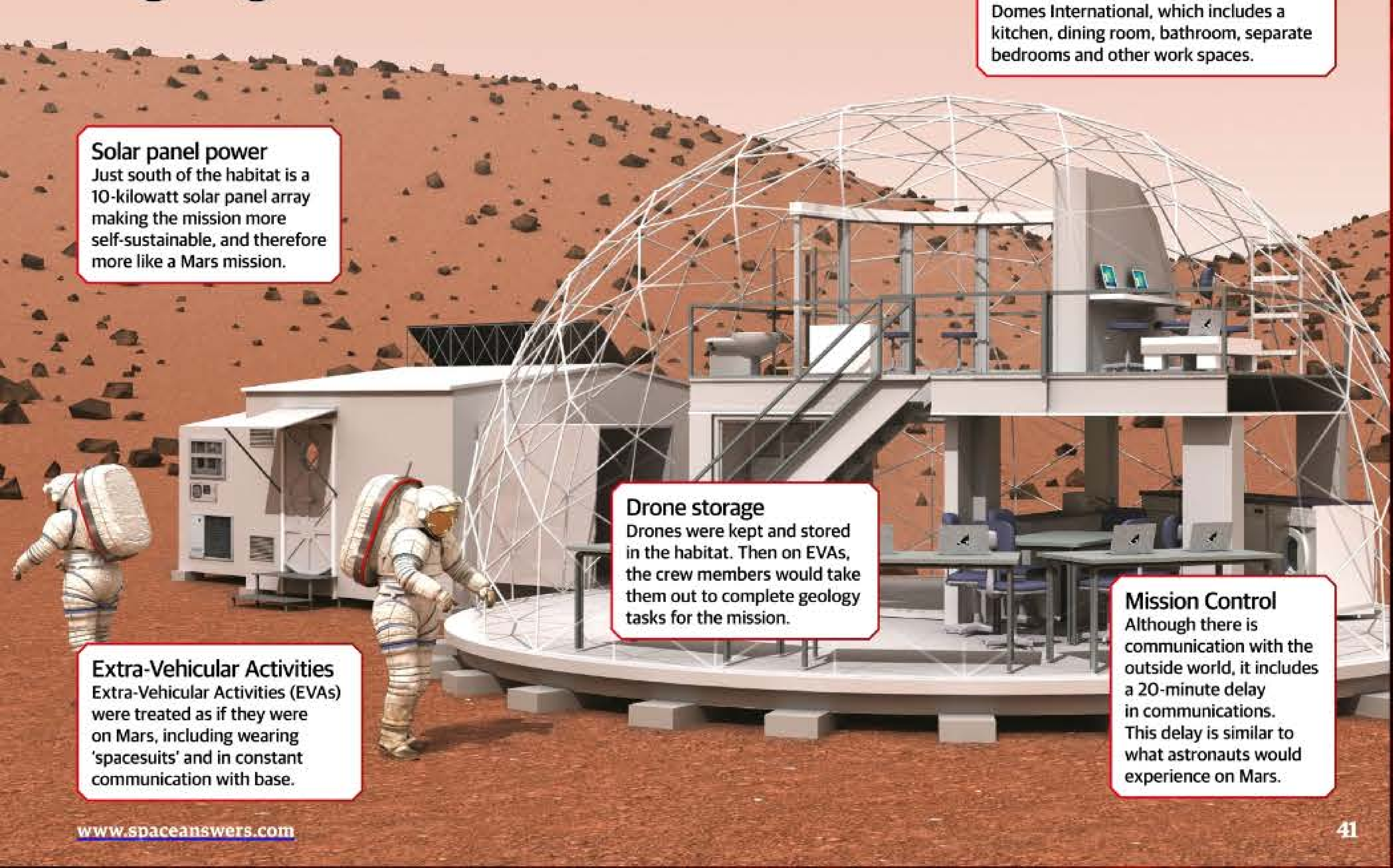
Storage module
The four compartments in this module consist of a refrigerated area, an area for non-perishable foods, an experimental greenhouse and an area containing a bathroom, sauna and a gym.

the surrounding desert sand to 3D print the walls of its future in-built museum. This efficiency will be essential when it comes to erecting a sanctuary on Mars, as it means that the raw materials won't have to travel on the spacecraft, saving fuel or making room for more important items or supplies.

The Mars Science City will also include an experimental aspect that will involve a team living in this simulated Mars city for one year. Although it differs from the previous psychological and physiological objectives that Mars-500 and HI-SEAS were tackling, the Mars Science City experiments will hope to improve upon the self-sustainability in energy, water and food – the essentials for life.

The collective ambitions of these projects, lest we forget the constant variety of experiments being conducted on the International Space Station, all have one common goal in mind, and that is to finally get humans on to, and eventually colonise, another planet. The task is arduous, there is no doubt about that, but it is possible. However, it is only possible as a collaborative effort, and that involves the development of a habitat that manipulates the Martian environment to our needs. Not only that, but the interaction of the crew is of the utmost importance to ensure a high work rate and efficiency. By gaining a collective insight on what it's like to travel to Mars, build a structure there and then survive there, the human race gets ever closer to the dream of a 'Mars City'.

Highlights of HI-SEAS



The home dome
The habitat dome was supplied by Pacific Domes International, which includes a kitchen, dining room, bathroom, separate bedrooms and other work spaces.

Solar panel power
Just south of the habitat is a 10-kilowatt solar panel array making the mission more self-sustainable, and therefore more like a Mars mission.

Drone storage
Drones were kept and stored in the habitat. Then on EVAs, the crew members would take them out to complete geology tasks for the mission.

Mission Control
Although there is communication with the outside world, it includes a 20-minute delay in communications. This delay is similar to what astronauts would experience on Mars.

Extra-Vehicular Activities
Extra-Vehicular Activities (EVAs) were treated as if they were on Mars, including wearing 'spacesuits' and in constant communication with base.

Deep Space

Black planets, cosmic mysteries and galactic dwarves

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Explorer's Guide

Eris

Forgotten in the outskirts of the Kuiper Belt, the dwarf planet could prove to be an intriguing destination

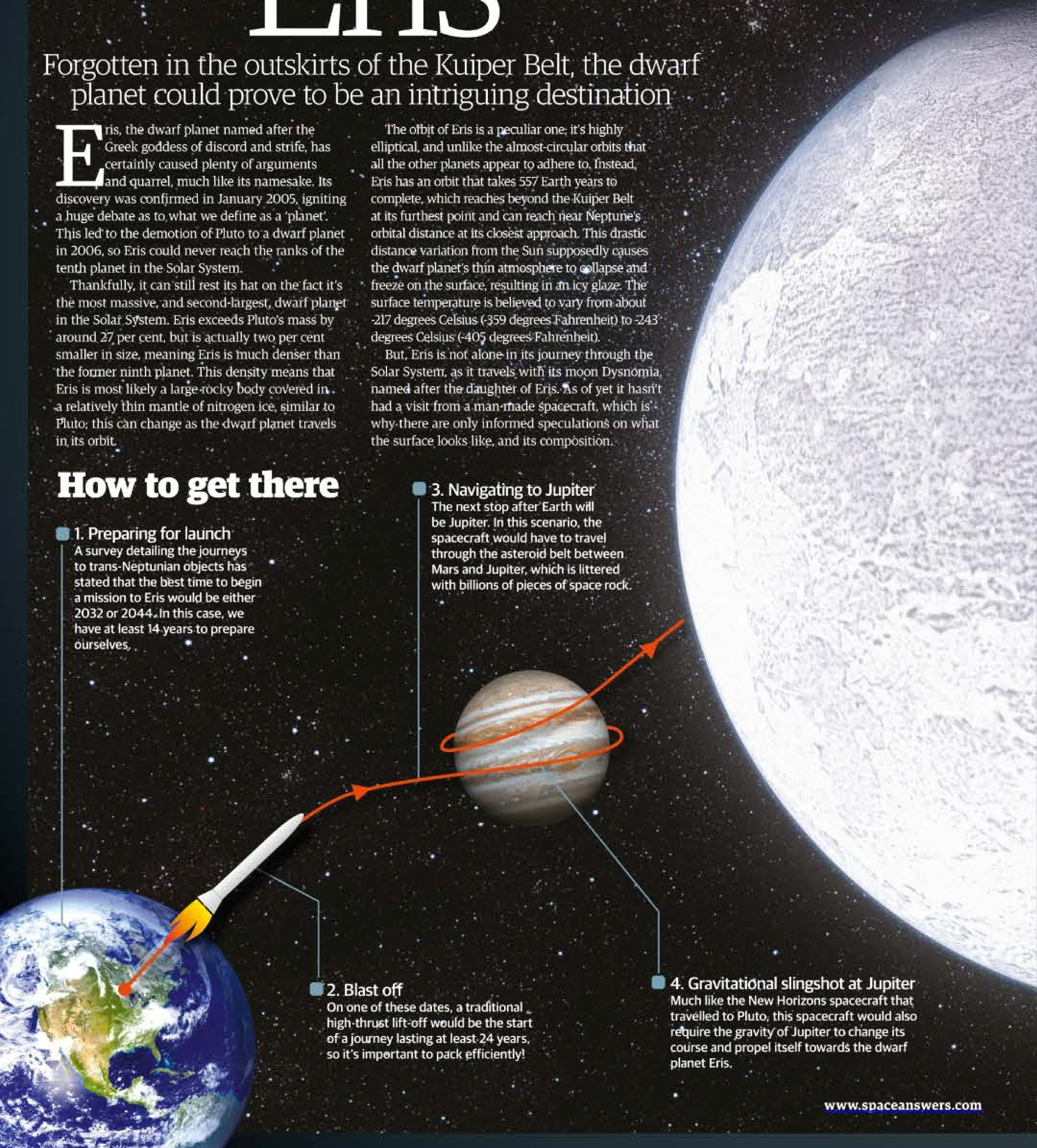
Eris, the dwarf planet named after the Greek goddess of discord and strife, has certainly caused plenty of arguments and quarrel, much like its namesake. Its discovery was confirmed in January 2005, igniting a huge debate as to what we define as a 'planet'. This led to the demotion of Pluto to a dwarf planet in 2006, so Eris could never reach the ranks of the tenth planet in the Solar System.

Thankfully, it can still rest its hat on the fact it's the most massive, and second-largest, dwarf planet in the Solar System. Eris exceeds Pluto's mass by around 27 per cent, but is actually two per cent smaller in size, meaning Eris is much denser than the former ninth planet. This density means that Eris is most likely a large rocky body covered in a relatively thin mantle of nitrogen ice, similar to Pluto; this can change as the dwarf planet travels in its orbit.

The orbit of Eris is a peculiar one; it's highly elliptical, and unlike the almost-circular orbits that all the other planets appear to adhere to. Instead, Eris has an orbit that takes 557 Earth years to complete, which reaches beyond the Kuiper Belt at its furthest point and can reach near Neptune's orbital distance at its closest approach. This drastic distance variation from the Sun supposedly causes the dwarf planet's thin atmosphere to collapse and freeze on the surface, resulting in an icy glaze. The surface temperature is believed to vary from about -217 degrees Celsius (-359 degrees Fahrenheit) to -243 degrees Celsius (-405 degrees Fahrenheit).

But, Eris is not alone in its journey through the Solar System, as it travels with its moon Dysnomia, named after the daughter of Eris. As of yet it hasn't had a visit from a man-made spacecraft, which is why there are only informed speculations on what the surface looks like, and its composition.

How to get there

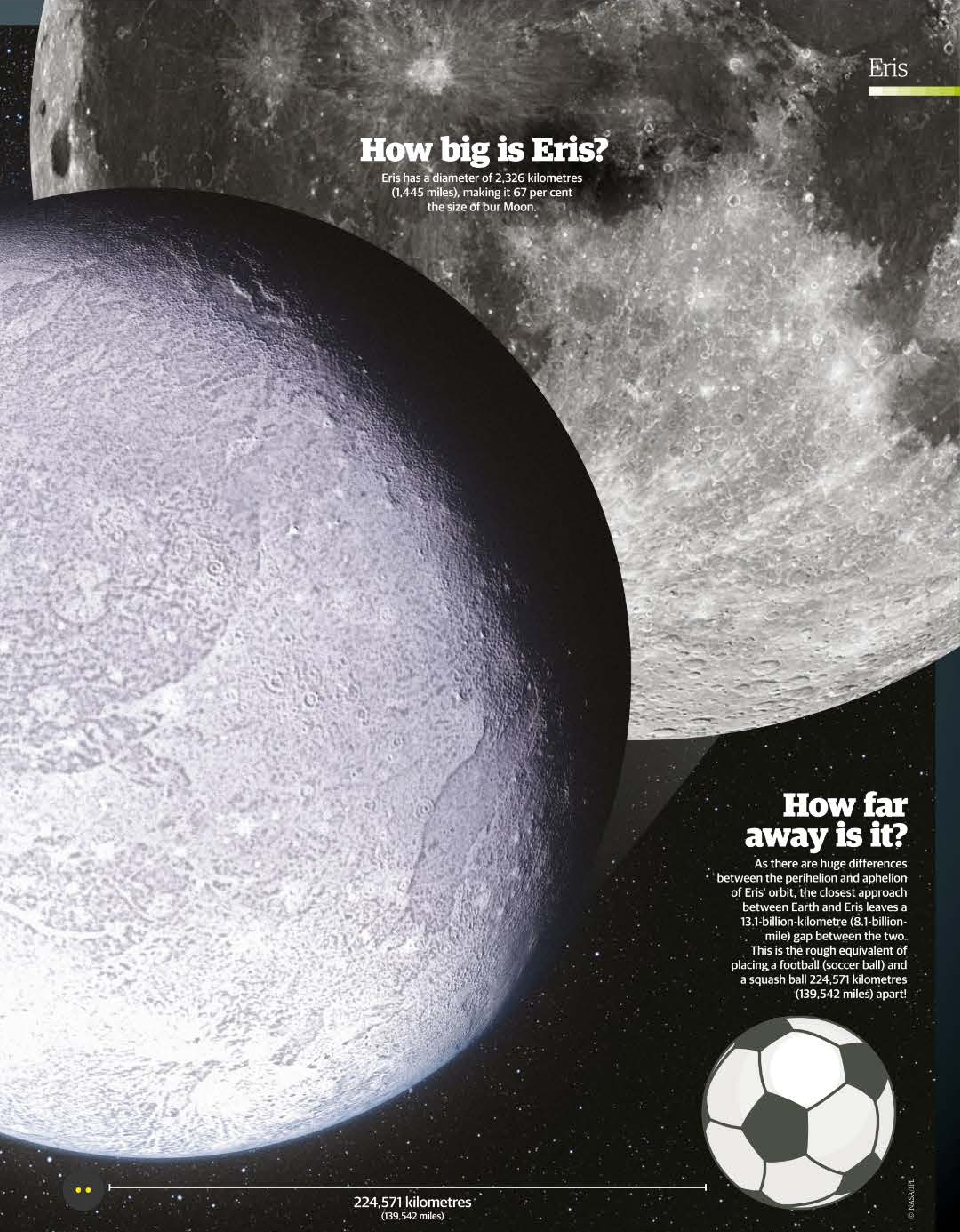


1. Preparing for launch
A survey detailing the journeys to trans-Neptunian objects has stated that the best time to begin a mission to Eris would be either 2032 or 2044. In this case, we have at least 14 years to prepare ourselves.

2. Blast off
On one of these dates, a traditional high-thrust lift-off would be the start of a journey lasting at least 24 years, so it's important to pack efficiently!

3. Navigating to Jupiter
The next stop after Earth will be Jupiter. In this scenario, the spacecraft would have to travel through the asteroid belt between Mars and Jupiter, which is littered with billions of pieces of space rock.

4. Gravitational slingshot at Jupiter
Much like the New Horizons spacecraft that travelled to Pluto, this spacecraft would also require the gravity of Jupiter to change its course and propel itself towards the dwarf planet Eris.



How big is Eris?

Eris has a diameter of 2,326 kilometres (1,445 miles), making it 67 per cent the size of our Moon.

How far away is it?

As there are huge differences between the perihelion and aphelion of Eris' orbit, the closest approach between Earth and Eris leaves a 13.1-billion-kilometre (8.1-billion-mile) gap between the two. This is the rough equivalent of placing a football (soccer ball) and a squash ball 224,571 kilometres (139,542 miles) apart!

© NASA/JPL

Top sights to see on Eris

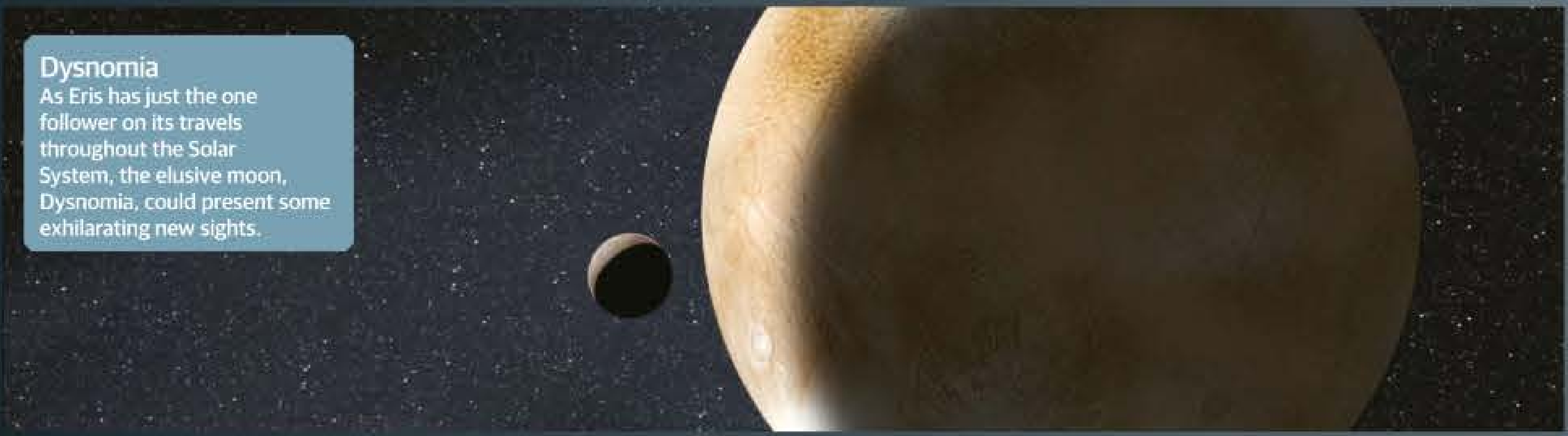
There has been no visit made to Eris by a man-made spacecraft as of yet, and our telescopes are unable to decipher the true details of this elusive and dwarf planet. Scientists have only been able to estimate the properties of Eris, but what we do know does present a few opportunities for marvellous sights that wouldn't be seen on Earth.

As Eris continues on its 557-year voyage around the Sun, part of this will be through the minefield of space rock and icy bodies known as the Kuiper Belt, which lies beyond the orbit of Neptune. To see what lurks around in the darkest, coldest and most dangerous region in the Solar System would be a thrill in itself. These pieces of space rock could also prove to be the oldest material in the Solar System, answering several vital questions regarding the origins of life.

Dysnomia, the moon of Eris, is a piece of space rock gravitationally bound to the most massive dwarf planet in the Solar System. Since its discovery in 2005 by astronomers using the Keck Observatory in Mauna Kea, Hawaii, astronomers have not been able to deduce where it came from. However, they have deduced that it is about a quarter the size of Eris and it completes one orbit every 16 days. When measuring the albedo - the measure of reflectivity of sunlight - of Dysnomia, astronomers deduced it has an albedo over four-times less than Eris, meaning it has a much darker surface. This would mean that only upon closer inspection of the lone moon would we be able to unveil exciting and transformative information.

The surface of the dwarf planet has been heavily studied since its discovery, but its true nature has not been fully revealed, although some clues have arisen that could lead to an interesting discovery about Eris. For instance, due to its similar, but denser, physical properties, as well as the fact it is a trans-Neptunian object (TNO), astronomers believe it could physically resemble Pluto. It is possible that nitrogen ice covers the surface, which is what gives it the much shinier surface than Dysnomia.

Recent studies have even suggested that there could be some sort of cryovolcanism occurring on Eris that replenishes the surface. This occurrence has raised the question of what is powering this geological activity. Scientists have suggested that it could be radioactive rocks near the core which are heating the interior and causing the volcanoes to erupt frozen nitrogen.



Dysnomia
As Eris has just the one follower on its travels throughout the Solar System, the elusive moon, Dysnomia, could present some exhilarating new sights.

Kuiper Belt
Eris makes the trip through the far-out Kuiper Belt in its orbit. This belt contains the oldest comets and asteroids left over from the formation of the Solar System.

Pluto-like surface
Many scientists have speculated that due to the similar size, density and orbital position of Eris, its surface could resemble Pluto's. Unfortunately, this hasn't been confirmed yet.

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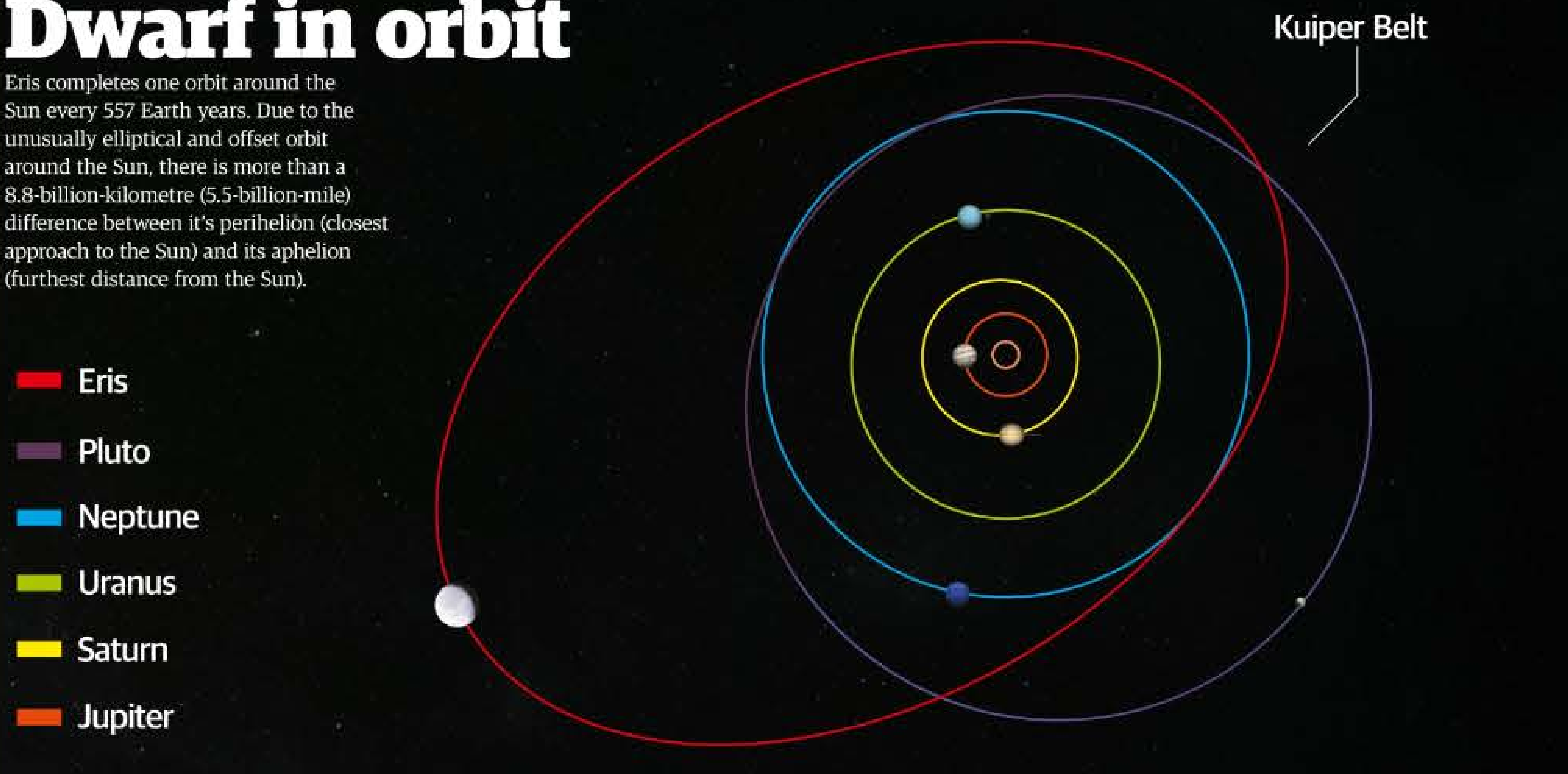
Dwarf in orbit

Eris completes one orbit around the Sun every 557 Earth years. Due to the unusually elliptical and offset orbit around the Sun, there is more than a 8.8-billion-kilometre (5.5-billion-mile) difference between it's perihelion (closest approach to the Sun) and its aphelion (furthest distance from the Sun).



Eris in numbers

97x

How much further away from the Sun it is compared to Earth at its aphelion

2003

The year that Eris was first observed

Eris' weather

-243°C
-405°F

Get ready for a cold trip! Due to the vast distance between the dwarf planet and the Sun, its surface temperature reaches temperatures as low as -243 degrees Celsius (-405 degrees Fahrenheit). This causes the atmosphere to freeze on the surface, but it will begin to thaw as it gets closer to the Sun.

1

Number of moons orbiting Eris

0.43

The eccentricity of Eris' orbit

25.9

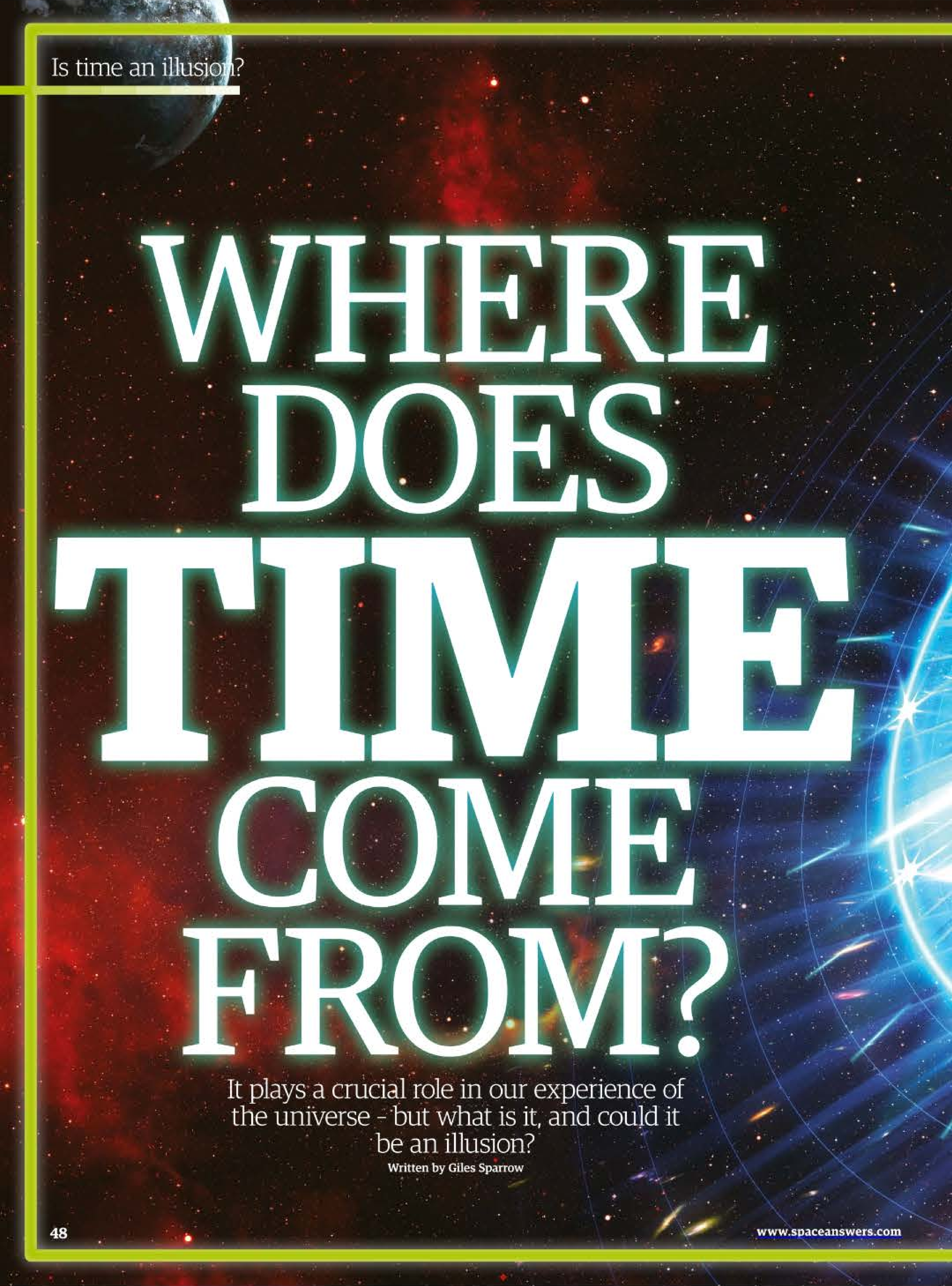
The time - in hours - it takes Eris to complete one rotation of the Sun

9th

Most massive known object orbiting the Sun

16

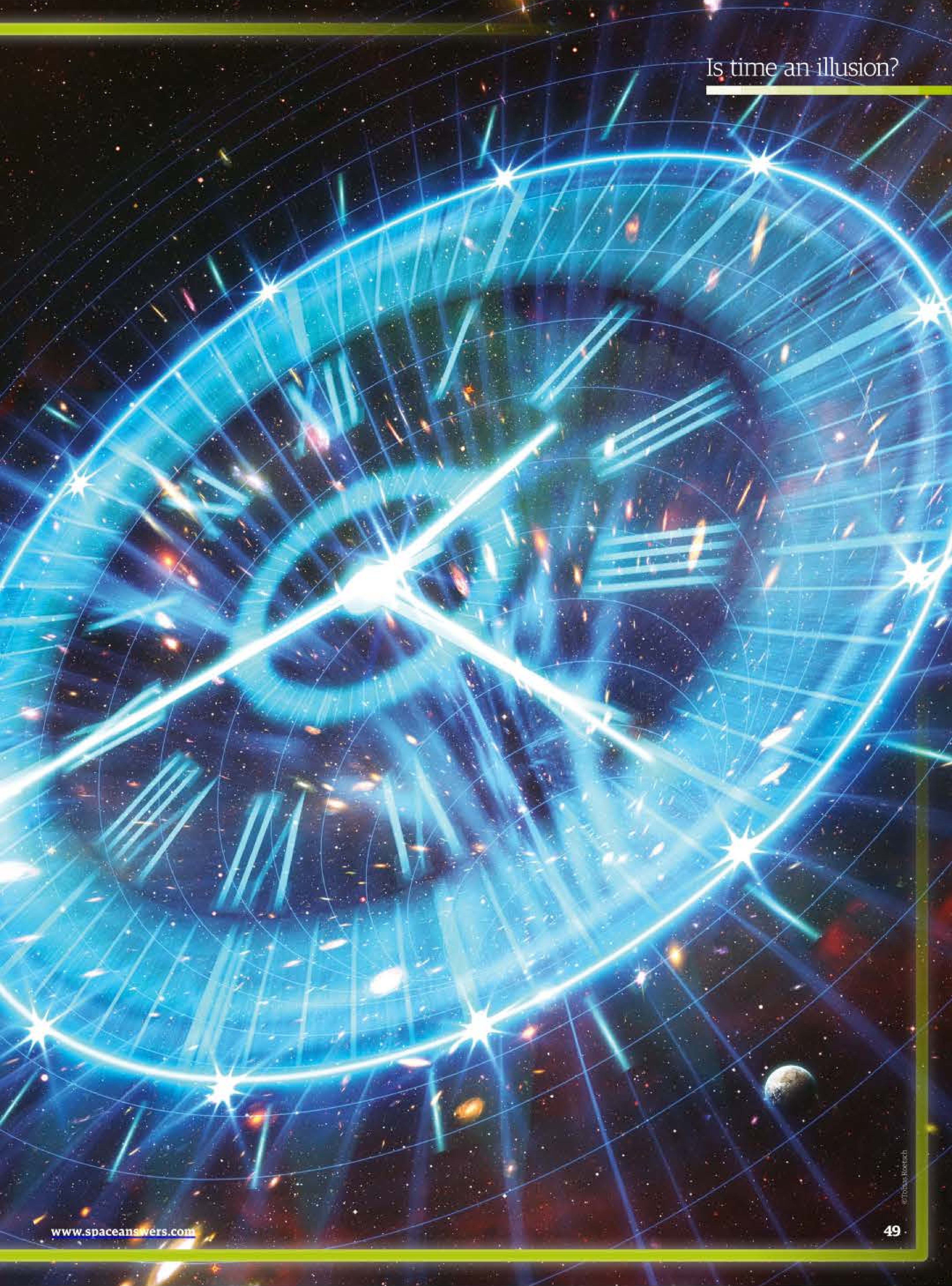
Earth days for Dysnomia to orbit Eris



WHERE DOES TIME COME FROM?

It plays a crucial role in our experience of the universe - but what is it, and could it be an illusion?

Written by Giles Sparrow



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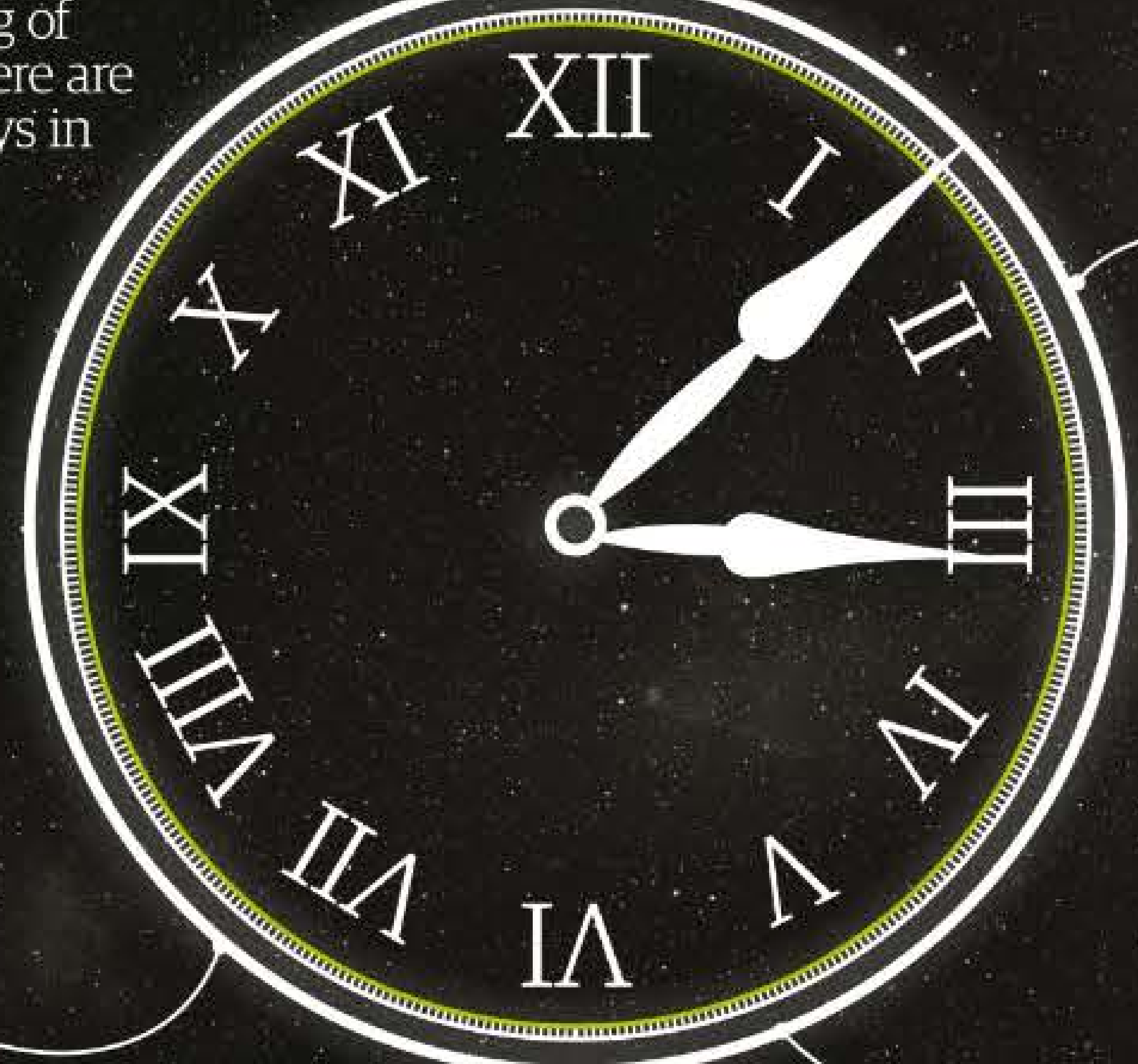
What don't we get about time?

Cosmologists think they have a pretty good understanding of time as a dimension, but there are still questions about the ways in which we experience time



Why can't we move back in time?
In theory, general relativity permits movement along 'closed timeline curves' that could take a person back in time. But why is it that, in practice, the equations never seem to work out?

Do we really have free will?
Do we really have the ability to make unfettered choices about future events, or are we simply following a predetermined course without being aware of it?

Why don't we remember the future?
Some physicists think that our ability to form memories is linked to an increase of entropy in our brains, but there's still no comprehensive theory for how this could work.

Time is a constant part of our everyday lives - even as you read this sentence, its first words have disappeared into the past while the next paragraph looms up from the future. We're so used to the experience of flowing time that we very rarely stop to think about what it really is or why it works in the way that it does.

While most cosmologists agree that time is an innate feature of the universe with its direction defined only by other laws of physics, a controversial new theory suggests that its flow could be driven by the fact that our universe is expanding - an idea which means that, at least in theory, time could one day be thrown into reverse.

Fortunately, even though time is hard to visualise, scientists have a well-established way of treating it as a fourth dimension: a direction in which phenomena can change their location, similar to the familiar three dimensions that locate objects in space.

"Time is not that hard to understand," says Professor Sean Carroll, research professor at the California Institute of Technology and author of *From Eternity to Here: The Quest for the Ultimate Theory of Time*, optimistically. "I don't think it's a mystery, and I don't think it's been a mystery for a very long time. It was a bit simpler back when we had Isaac Newton and time and space were both absolute. Then we would have considered the universe to be made of space and everything in it, and the universe keeps happening over and over again - time is just the label we put on those different versions that happen one after another with things in different positions, a bit like the pages of a book."

As he explains, our modern view of time - superseding Newton's - was shaped by the breakthroughs of Albert Einstein a little over a century ago: "In Einstein's view there's actually 'space-time' [a structure with four dimensions that determines how objects are located in the universe], and how an observer slices that space-time into time and space is a little arbitrary - different people can look at it in different ways, and no one is right and no one is wrong. But still, in any one point of view there's a sequence of moments. It's a little more complicated, but really it's not that hard - it's certainly no more profound to ask what time is, than-to-ask-than, what space is.

"I guess I'm smuggling in an eternalist point of view here, which treats every moment of time as on an equal footing, as opposed to a 'presentist' point of view that says only the world right now is real. In a post-Einstein world that's really not how many physicists think," he continues.

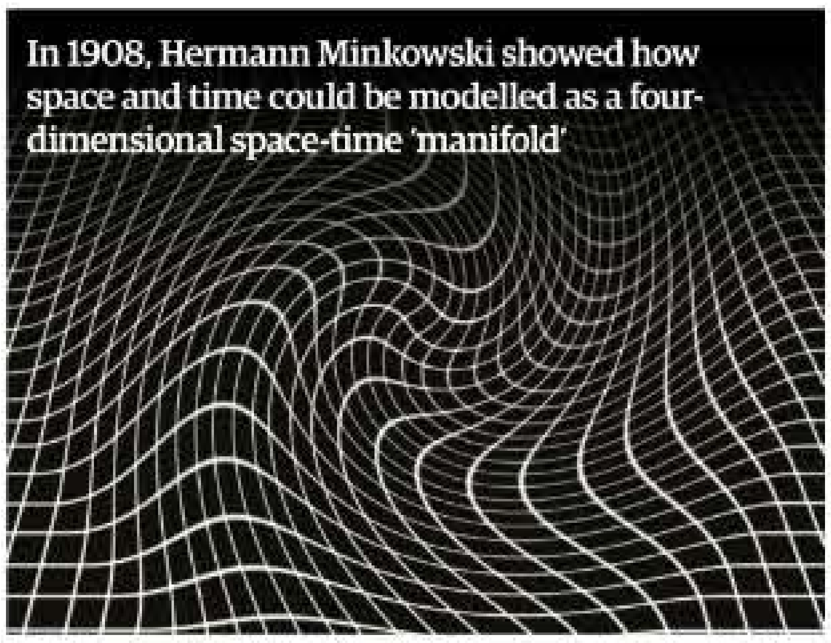
> "It's that riding the wave of the increasing entropy of the universe that gives us the perception of the flow of time" **Prof Sean Carroll**

General relativity allows flexibility in space-time, perhaps including the possibility of 'wormhole' tunnels between one region of space-time and another

But if every moment in time is equivalent, why can't we move back and forth in time at will - why does time only appear to flow in one direction, and does it really 'flow' at all?

"An important subtlety is the difference between time as a label on different points versus the 'arrow of time' - the fact that the past and future are different for us in a way that is not true for space," explains Carroll. "All directions in space are the same (at least outside the influence of gravity), but in time the two directions are very different, and there's just one direction that we go in."

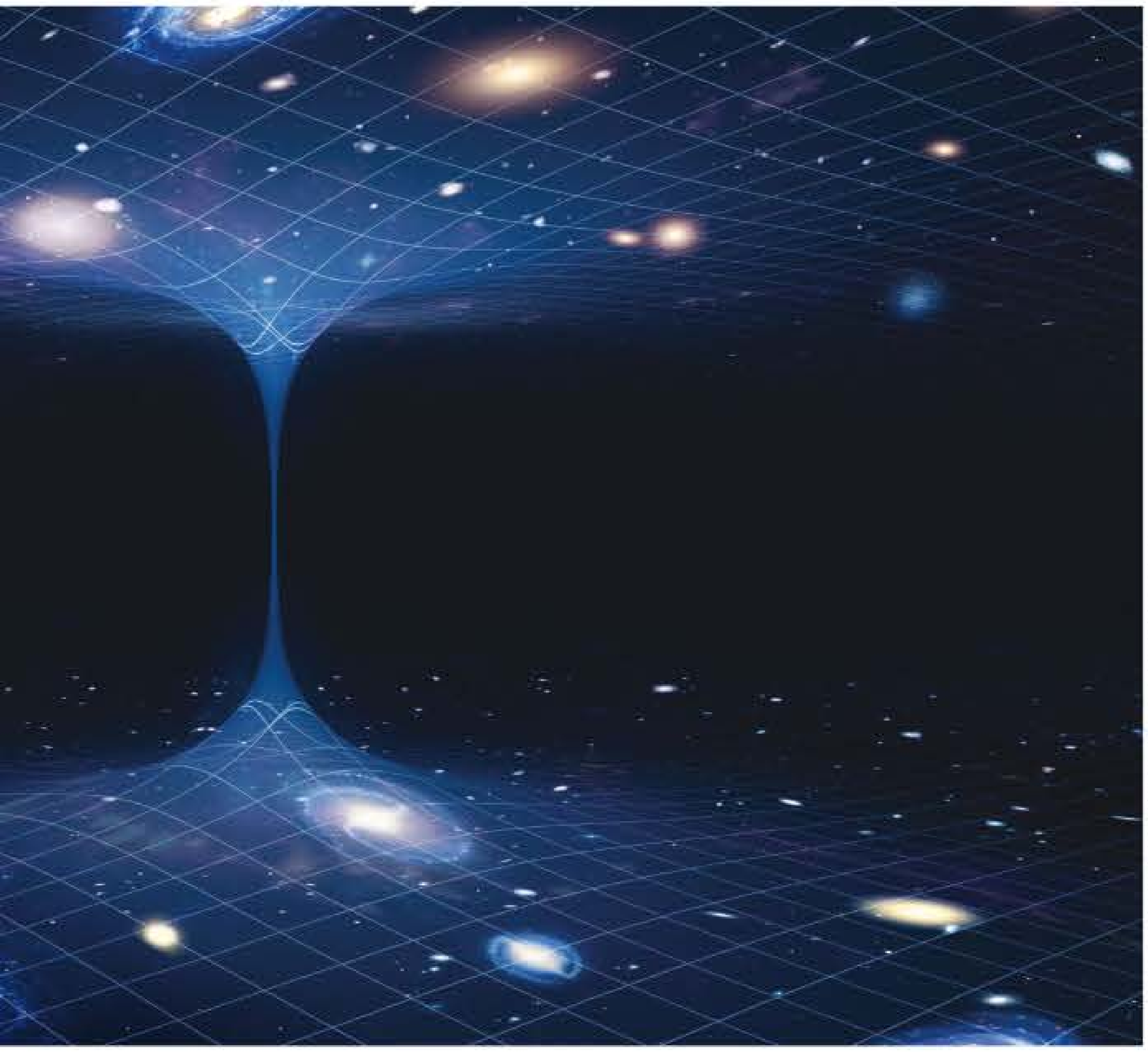
Ask most physicists about the arrow of time and they'll almost certainly explain it in terms of the second law of thermodynamics (the science that relates heat and energy, discovered and expanded upon during the 19th century). The second law is a simple statement that says the amount of disorder or 'entropy' in a closed system increases with time, unless energy is supplied to create more order.


In 1908, Hermann Minkowski showed how space and time could be modelled as a four-dimensional space-time 'manifold'

The system can be anything, and its entropy can be thought of as the 'useless' energy within it. A classic example is a pair of boxes containing hot and cold gases with a connecting door between them. At first this particular arrangement's entropy is low because most of its energy is in useful form - locked up in hot, fast-moving gas molecules in one box that could be used, for example, to pump an engine piston.

Open the door between the boxes, however, and over time the gas molecules of different temperature will inevitably mix together. Hotter gas molecules will collide with colder and slower-moving ones, transferring energy until eventually both boxes are filled with gas of an intermediate temperature. A once-orderly system with low entropy has now become a disorderly (high-entropy) system of jumbled molecules with less capacity to do useful work.

But what exactly does all this have to do with the direction of time? Well, according to current cosmology, the universe too can be thought of as a closed system - there's only so much energy to go around and no way of supplying energy from outside to reverse the rise of entropy. The universe therefore started out in a highly ordered, low-entropy state (the Big Bang era where all matter had uniformly high temperatures), and entropy



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Time's evolution

c. 3000 BCE
Keeping track of the seasons
Most living things on Earth have some conscious or unconscious 'time sense' in the form of adaptations to the seasonal cycles as Earth moves around the Sun.

c. 2000 BCE
Water clocks
The first devices used to keep track of shorter periods were water clocks. These estimated the passage of time through the accumulation of steady drips of water.

c. 1500 BCE
Sundials
First used in ancient Egypt, sundials keep time by tracking the path of the Sun's shadow. Differences in its path throughout the year make them inaccurate, though.

c. 3000 BCE - 1200 CE
Mechanical timekeepers
Sophisticated water clocks began to use escapement mechanisms that harnessed the power of falling water and released it in small regulated movements.

1656
The first pendulum clock
Dutch scientist Christiaan Huygens saw that a pendulum of a fixed length always swings with the same period, regardless of the arc of its swing. Using weights and an escapement to keep it moving, he developed a more accurate timekeeper.

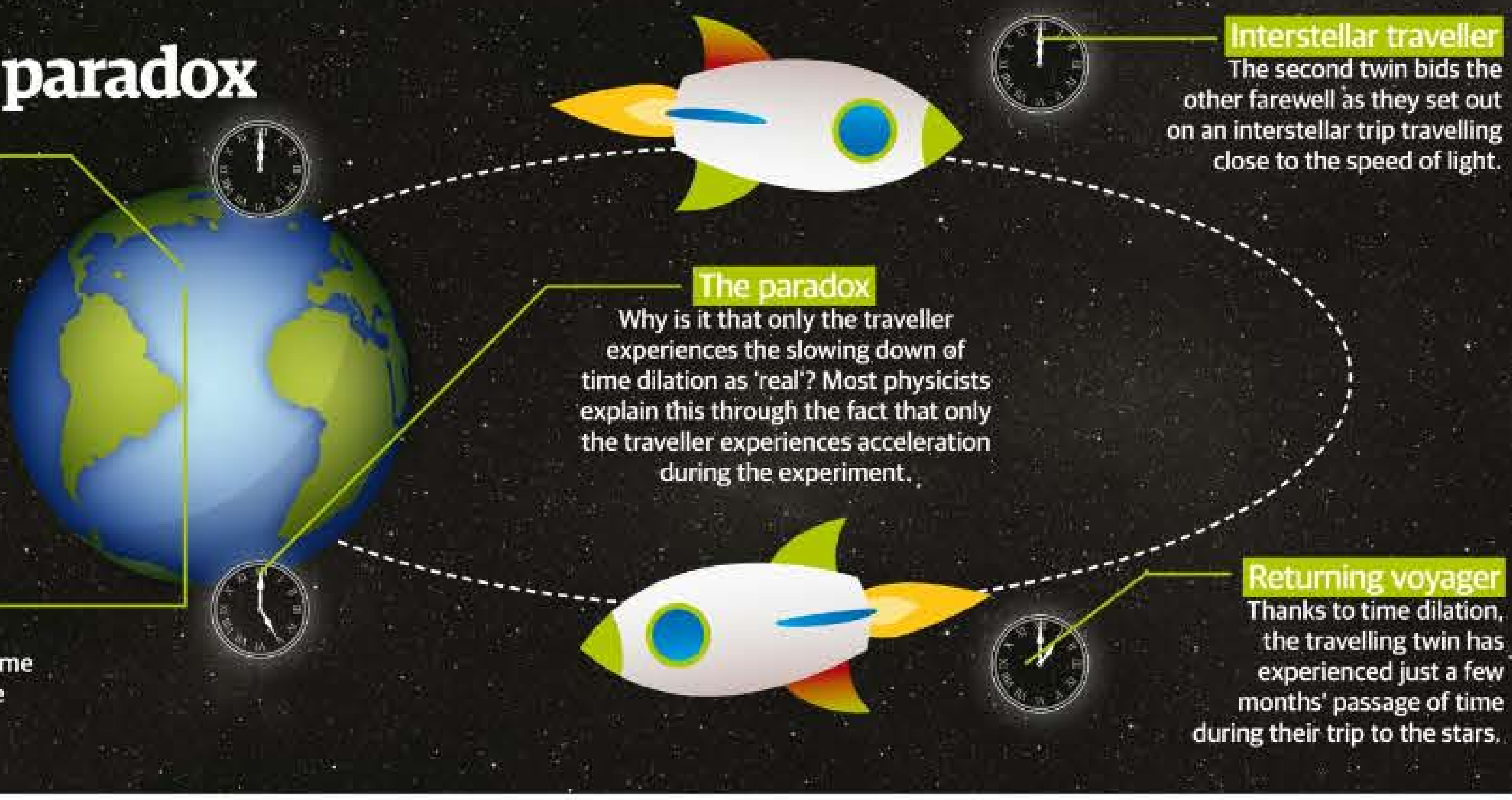
17th-18th century
The longitude problem
If sailors knew the time at home port they could work out their position on Earth from observations. Finding a timekeeper that worked at sea proved a struggle.

1735-61
The marine chronometer
Yorkshire clockmaker John Harrison built a series of increasingly accurate timepieces that could be used at sea, solving the longitude problem.

1927
Quartz vibrations
In 1927, engineers at Bell Laboratories in the US worked out how to use quartz crystals to generate extremely regular vibrations that could drive a clock.

1955
Atomic clocks
Louis Essen and Jack Parry of the UK's National Physical Laboratory built the first accurate atomic clock. They are used as the ultimate scientific timekeepers.

The twin paradox



Stay at home twin
We start out with a pair of identical twins. One remains on Earth.

Interstellar traveller
The second twin bids the other farewell as they set out on an interstellar trip travelling close to the speed of light.

The paradox
Why is it that only the traveller experiences the slowing down of time dilation as 'real'? Most physicists explain this through the fact that only the traveller experiences acceleration during the experiment.

Years later
The twin on Earth has experienced decades of time and grown old by the time the sibling returns.

Returning voyager
Thanks to time dilation, the travelling twin has experienced just a few months' passage of time during their trip to the stars.

has been increasing ever since. Today, much of its matter is still concentrated in low-entropy systems such as stars, but in the far future, as succeeding generations of stars burn out, the cosmos will succumb to 'heat death' in which matter and energy become more and more evenly and thinly spread.

"In my perspective, the arrow of time just comes from the fact that the entropy of the universe was smaller in earlier times and grows larger at later times. There's nothing propelling the universe forward in time, it's just you have all these different moments distinguished by the rule that earlier means lower entropy, later means higher entropy,' explains Carroll. "That explains why you can remember the past and not the future, why you can make choices about the future but not about the past and so forth. There are good reasons why a person, considered as a series of people at moments in time with increasing entropy, feels that time flows in that direction.

"It's more of a psychological effect than anything else - we carry around in our minds a moving image of what we were a second ago, what we will be a second from now, and we're constantly updating on the basis of what we learn, how our surroundings change and so on. It's that riding the wave of the increasing entropy of the universe that gives us the perception of the flow of time. If, however, the idea is that there's some active element of reality that pushes the universe forward in time to bring about change, then that's not really part of physics as we understand it."

Nevertheless, that possibility of a 'driving force' behind the flow of time is where a controversial new idea put forward by physicist Richard Muller of the University of California, Berkeley could come into play. Muller's own 2016 book, *Now: The Physics of Time*, suggests that time is a real phenomenon, and that more time is created as space itself grows.

While Carroll and many other cosmologists are doubtful about the need for a driving force behind the arrow of time, Muller does at least put forward a plausible way of testing his proposal. The idea comes from gravitational waves - the minute distortions of space-time that ripple out across the universe from certain cataclysmic events involving large asymmetric masses.

Although such waves were predicted by Einstein in the early 20th century, they have only been detected at the super-sensitive Laser Interferometer Gravitational-Wave Observatory (LIGO) in the past couple of years. Muller and his Caltech collaborator Shaun Maguire argue that because the black hole collisions that generate gravitational waves create 'new' space, they should also create a small amount of new time. What's more, the quantities of time involved (around a millisecond) are large enough to be measurable using existing LIGO instruments, so Muller's intriguing hypothesis could either be proved wrong or pass its first observational test in the relatively near future.

While Muller's model of time is a radical departure from those supported by the majority of cosmologists, the way it makes the flow of time 'real', rather than something merely defined by the increase of entropy, gives it an obvious intuitive appeal. Technically, the difference between the roles of time and those of other dimensions is its lack of 'symmetry'. Physicists define symmetry as the property of a system that remains unaltered by a 'transformation' or movement in terms of one or more dimension. A system can be transformed

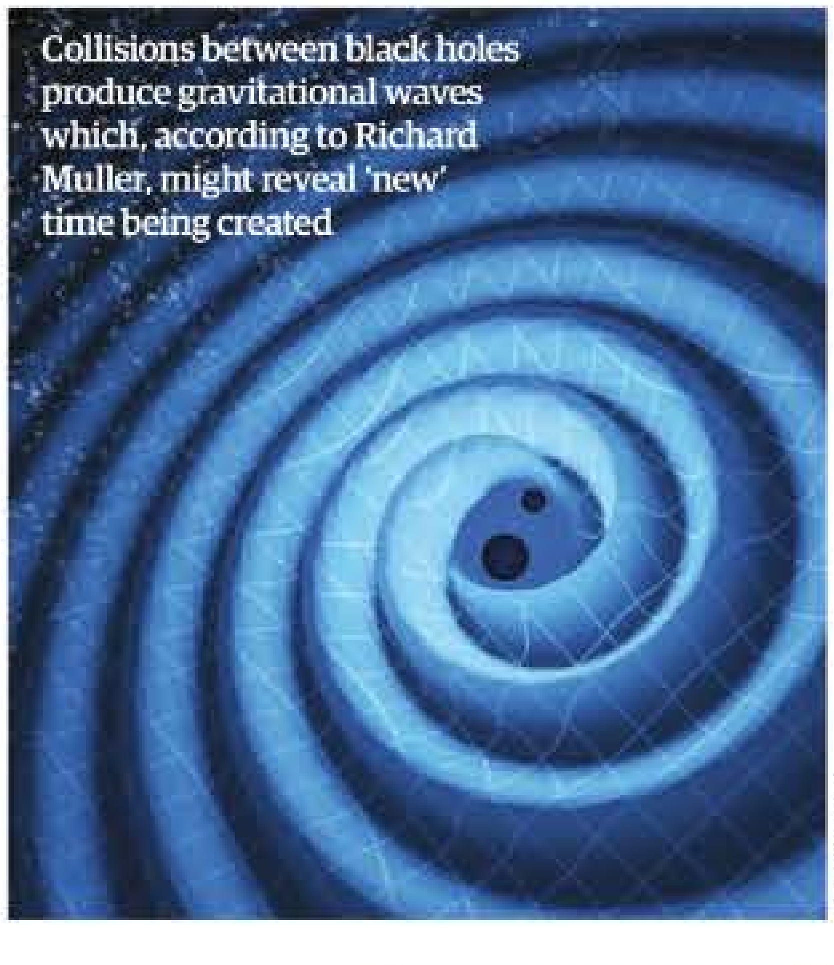
The arrow of time

Another way of looking at the arrow of time is through the lens of possibilities - when we say that 'entropy increases', we mean that things have a wider variety of possible states in the future than they do in the past

An orderly egg
An unbroken egg can be unbroken and perfect in just one way - so we can say that it has relatively low entropy.

Network of cracks
If we crack the egg, its shell can break in different ways - the cracked egg has higher entropy than the whole one.

Smashed to bits
Dropping the egg breaks it apart and can result in a wide variety of different results (highest entropy). If we pick up all the pieces and drop them again, the egg will never reassemble itself.



Collisions between black holes produce gravitational waves which, according to Richard Muller, might reveal 'new' time being created

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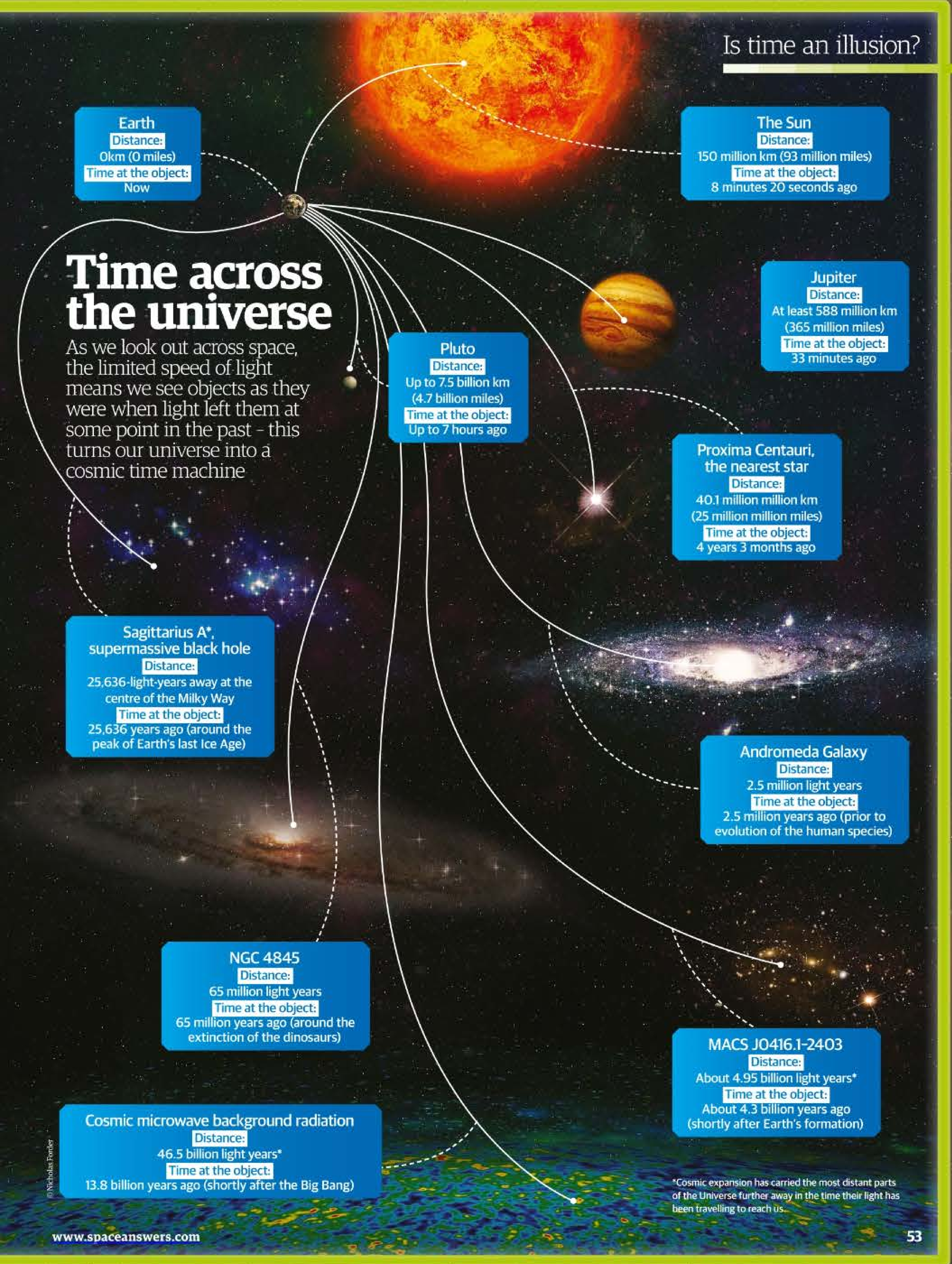
Time across the universe

As we look out across space, the limited speed of light means we see objects as they were when light left them at some point in the past – this turns our universe into a cosmic time machine



Earth
Distance:
0km (0 miles)
Time at the object:
Now

The Sun
Distance:
150 million km (93 million miles)
Time at the object:
8 minutes 20 seconds ago

Jupiter
Distance:
At least 588 million km (365 million miles)
Time at the object:
33 minutes ago

Pluto
Distance:
Up to 7.5 billion km (4.7 billion miles)
Time at the object:
Up to 7 hours ago

Proxima Centauri, the nearest star
Distance:
40.1 million million km (25 million million miles)
Time at the object:
4 years 3 months ago

Sagittarius A*, supermassive black hole
Distance:
25,636-light-years away at the centre of the Milky Way
Time at the object:
25,636 years ago (around the peak of Earth's last Ice Age)

Andromeda Galaxy
Distance:
2.5 million light years
Time at the object:
2.5 million years ago (prior to evolution of the human species)

NGC 4845
Distance:
65 million light years
Time at the object:
65 million years ago (around the extinction of the dinosaurs)

MACS J0416.1-2403
Distance:
About 4.95 billion light years*
Time at the object:
About 4.3 billion years ago (shortly after Earth's formation)

Cosmic microwave background radiation
Distance:
46.5 billion light years*
Time at the object:
13.8 billion years ago (shortly after the Big Bang)

© Nicholas Forder

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*Cosmic expansion has carried the most distant parts of the Universe further away in the time their light has been travelling to reach us.

"If you have a universe that expands and cools and empties out, then that empty universe can last forever" **Sean Carroll**

© SpaceX/Science Photo Library

across the three space dimensions without any effect, so it can be thought of as 'space symmetric' - but the same system is unlikely to be symmetric in time - interactions that increase entropy are inherently more likely than those which reduce it; omelettes rarely reassemble themselves into eggs!

Muller argues that his "Now model" explains the asymmetry of time, whereas traditional cosmology merely defines it by the increase of entropy. Carroll acknowledges the problem, but offers an alternative solution that develops naturally from another hot topic in modern cosmology: "The reason the symmetry problem is so difficult is that you have to start from the idea that the fundamental laws of physics don't play favourites with one direction or the other," he explains. "People again and again fall into the trap of inventing some feature of the Big Bang that purports to explain why the universe had such a low entropy - but they don't explain why that special feature of the past shouldn't also apply to the future."

Carroll's solution, working with his then-graduate student Jennifer Chen, was to look at the problem through the lens of 'eternal inflation'. This is the idea that our universe is not unique, but is merely one among an infinite succession of space-time bubbles that can form and develop spontaneously. "What we did was to say maybe the reason why entropy is increasing is because entropy can always increase. If you treat the universe as a box of gas, then the entropy in the box just goes up and stays there, but if the entropy can always increase, then it becomes a little more natural that we see it increasing - it never saturates," he tells us.

The LIGO experiment tunnels in Louisiana and Washington capture minute shifts in the dimensions of space caused by gravitational waves as they pass through the Earth

"So in that case, why should the way entropy increases look like our Big Bang at the beginning, and develop from there? We suggested that the way the universe increases its entropy is through the creation of baby universes. If you have a universe like ours that expands and cools and empties out, then that empty universe can last forever. Nothing happens in it, but for each tiny region there's a finite possibility in a given time that it disconnects into a little bubble that branches off and goes its own way," he continues. "That little bubble starts small and grows. You go from the old, featureless universe to that plus a bubble - adding that extra little bit increases the overall entropy, but the entropy in that bubble starts off small because it's easier to make a tiny bubble than a big one. Then as it carries on growing, the entropy increases."

In Carroll and Chen's model, the ever-increasing entropy of the universe arises simply because we're trapped inside one of these rapidly expanding bubble universes and unable to see beyond it thanks to the limited speed of light. Cosmic history therefore appears to originate in the low-entropy cosmic fireball of the Big Bang, with entropy increasing as the universe has expanded ever since. Time retains its role as a dimension similar to the three of space, but the arrow of time and increasing energy mean that we can remember the past and make choices (or at least, have an illusion of free will) about the future. "I don't know if this scenario is true," reflects Carroll, "but I would say it's the only one I've ever seen that doesn't beg the question by adding some asymmetry between the early universe and the present."

It's perhaps too soon to say whether Muller's hypothesis of constantly created time, Carroll's explanation for increasing entropy in an eternal universe or some other entirely new theory will ultimately explain the origin of time, but we can all hope that, just as entropy increases, so too will our understanding of this intriguing phenomenon, and our complex relationship with it.

One of the most famous effects of relativity is time dilation: the slowing down of time for objects moving at high speed, relative to observers viewing them from outside

© Tobias Roetsch

THE DARK PLANET

One of the hottest exoplanets ever found is also now one of the blackest as well. **All About Space** uncovers the reason why...

Written by Lee Cavendish

What do we really know about planets beyond our Solar System? It has been 25 years since our first detection of an exoplanet and there's still so much more we're keen to know about these distant worlds. In 1992, the first exoplanet was discovered orbiting a pulsar, a neutron star rotating at rapid speeds. Obviously any planet orbiting this kind of star would be inhospitable to life as we know it, principally due to the intense radiation would rain down upon the surface.

It wasn't until 6 October 1995 where Michel Mayor and Didier Queloz of the University of Geneva discovered the first exoplanet orbiting a main sequence star. The finding was a revelation, as it confirmed what were only 'sci-fi' speculations at the time; that there are other worlds beyond our solar neighbourhood. Orbiting a Sun-like star, some 50 light years away, astronomers found the gas planet to be 50 per cent larger than Jupiter and dubbed it 51 Pegasi b. Also known as Dimidium, the planetary giant was an anomaly to astronomers, as not only were its physical properties unusual to say the least, but the fact that it orbited its parent star at 7,800,000 kilometres (4,900,000 miles) a minute stumped them even further. The orbital distance is only 17 per cent that of Mercury's orbit, making the time taken to complete one revolution only four days! For a planet of this size to orbit a star at such a short distance from its stellar host defied most planetary formation theories.

Since then, the dicovery of exoplanets has come thick and fast, with missions such as the Kepler spacecraft, ground-based SuperWASP telescope, along with the space-faring Convection Rotation et Transits Planétaires (CoRoT) and Transiting Planets and Planetesimals Small Telescope (TRAPPIST) collating all the information they can in the search for other worlds. Most notably, the Kepler spacecraft has discovered over 5,000 exoplanet candidates, and almost half of them have been confirmed. Speaking back in 2016, Paul Hertz, the Astrophysics Division director at NASA Headquarters, says of the Kepler mission: "this knowledge informs the future

How does WASP-12b compare to Jupiter?

It may be a hot Jupiter, but there are some differences to the planetary king

WASP-12b

More enormous
WASP-12b is 80 per cent larger than Jupiter, with a radius of 125,140 km (77,758 miles).

Tight-knit orbit
WASP-12b orbits 3,440,000 kilometres (2,140,000 miles) from its stellar host, less than half a per cent of Jupiter's more-distant orbit.

Losing its mass
The host star is pulling material off WASP-12b at a rate of ten millionths of Jupiter's mass per year.

Reflecting barely any light
With an incredible low albedo of 0.064, this means that 94 per cent of the visible light is absorbed.

Scorching temperatures
The super-hot WASP-12b is 2,242 degrees Celsius (4,069 degrees Fahrenheit).

JUPITER

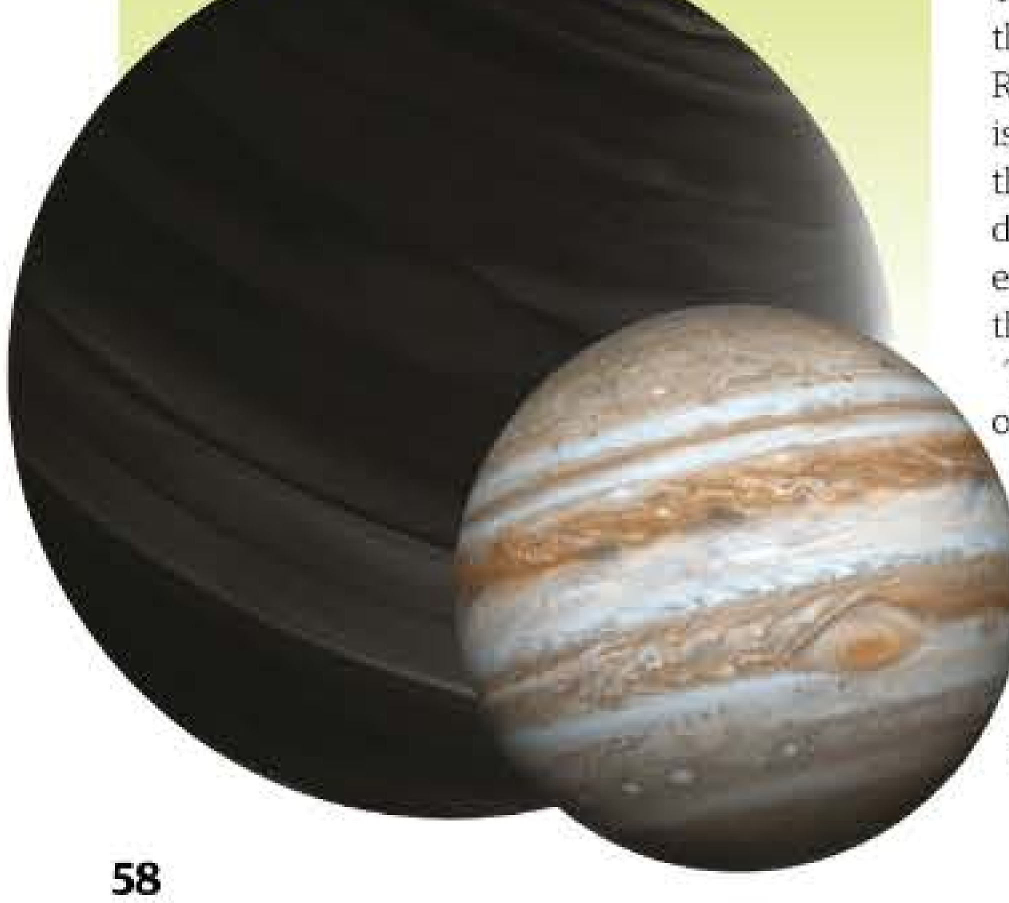
King of the Solar System
Jupiter is our Solar System's biggest planet, with a radius of 69,911 kilometres (43,440 miles).

Far-flung world
Jupiter is the fifth planet from the Sun, it sits five times further away from the Sun than Earth does.

Freezing clouds
Jupiter's cloud temperature is at a freezing cold minus 145 degrees Celsius (minus 229 degrees Fahrenheit).

Keeping its mass
As Jupiter sits incredibly far away from the Sun, it is not losing any mass due to a low intensity gravitational pull.

Reflective giant
Jupiter has an albedo of 0.343, which is five times more reflective than WASP-12b.



Hubble's STIS was fundamental in the discovery of WASP-12b's dark nature

> "Future missions are needed to take us ever-closer to finding out whether we are alone in the universe" **Paul Hertz**

missions that are needed to take us ever-closer to finding out whether we are alone in the universe."

This understanding of exoplanets has shaped our understanding of the universe, and astronomers have even been able to introduce categories for the different, unorthodox and exciting types of alien world. These types of exoplanets are based on their size, mass and orbital distance, ranging from 'gas giants' to 'super-Earths'. Astronomers were struck by the vast diversity of exoplanets, which completely shattered the idea that our Earth is special throughout the universe. And it all started with the emergence of 51 Pegasi b seeing in the birth of a different planetary flavour.

51 Pegasi b was categorised as a 'hot Jupiter' planet, due to its physical similarities to our Solar System's planetary king (its size and mass) and its short orbital distance, which causes the world to be extremely hot. Then, on 1 April 2008, one of the hottest exoplanets ever-discovered was found by the SuperWASP planetary transit survey and labelled WASP-12b. This hot Jupiter exoplanet has an average temperature of 2,242 degrees Celsius (4,069 degrees Fahrenheit), which is the almost five-times hotter than the surface temperature of Venus - the hottest planet in our Solar System. This scorching planet became apparent when the SuperWASP-North observatory, based in the Roque de los Muchachos Observatory on the island of La Palma, Canary Islands, Spain, watched the brightness of a star vary over the period of a day. This brightness variation occurs because the exoplanet orbits its host star and blocks out some of the starlight and known as a transit.

The team of astronomers, led by Dr Leslie Hebb of University of St. Andrews, spotted the transit of WASP-12b. They analysed it in much more thorough detail, hailing it as the hottest exoplanet known at the time. They found that this planet completes one orbit around its host star in 26.2 hours, making its orbit only six per cent the distance of Mercury's path. Due to this incredibly close proximity to yellow dwarf host star WASP-12, the planet is suspected to be tidally locked - this is where the intense gravity of the stellar host means only one side of WASP-12b faces its star at all times, with material being constantly stripped away.

The most recent work, led by Taylor Bell of the McGill University, Canada, has revealed that this particular hot Jupiter reflects practically no visible light, realising it to be a pitch-black planet. This new study has given WASP-12b a measured albedo (measure of reflectivity) of 0.064 to a certainty of 97.5 per cent - the same albedo of fresh asphalt. To compare this with some of our more familiar Solar System bodies, Earth has an albedo of 0.306, the Moon is 0.11 and the most reflective body in the Solar System, Enceladus, has an albedo of 0.8.

To fathom out the outlandish nature of the exoplanet, Bell and his team, including Dr. Nikolay Nikolov of the University of Exeter, harnessed the power of the Hubble Space Telescope's Space Telescope Imaging Spectrograph (STIS). This spectrograph collects the starlight from WASP-12, and then acts as a prism as it splits it into the basic wavelengths, known as its spectra. "With STIS we obtained spectra, which cover the near-ultraviolet

Enceladus has the highest albedo in our Solar System, with a value of 0.8

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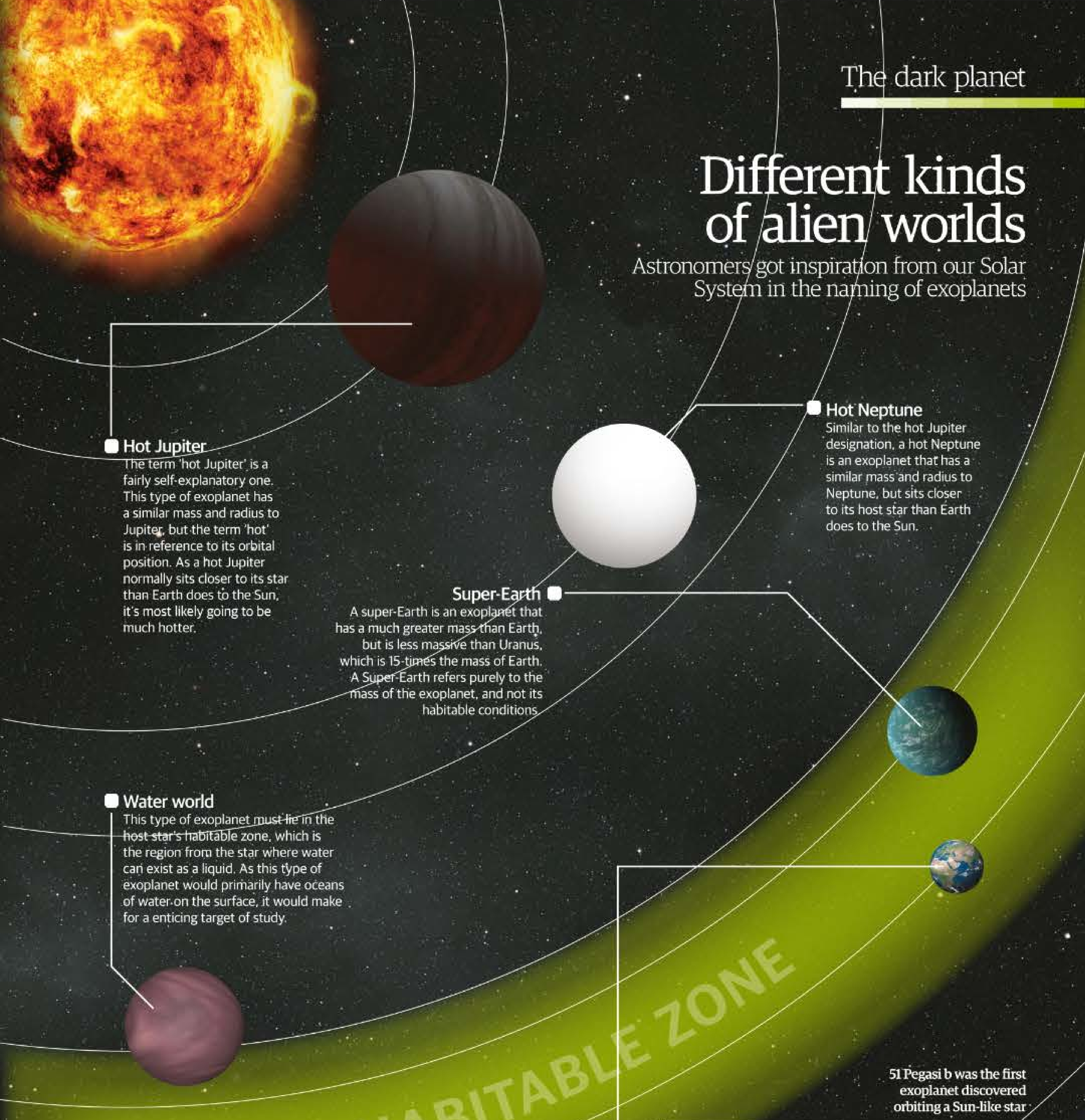
Different kinds of alien worlds

Astronomers got inspiration from our Solar System in the naming of exoplanets



Hot Jupiter

The term 'hot Jupiter' is a fairly self-explanatory one. This type of exoplanet has a similar mass and radius to Jupiter, but the term 'hot' is in reference to its orbital position. As a hot Jupiter normally sits closer to its star than Earth does to the Sun, it's most likely going to be much hotter.

Hot Neptune

Similar to the hot Jupiter designation, a hot Neptune is an exoplanet that has a similar mass and radius to Neptune, but sits closer to its host star than Earth does to the Sun.

Super-Earth

A super-Earth is an exoplanet that has a much greater mass than Earth, but is less massive than Uranus, which is 15-times the mass of Earth. A Super-Earth refers purely to the mass of the exoplanet, and not its habitable conditions.

Water world

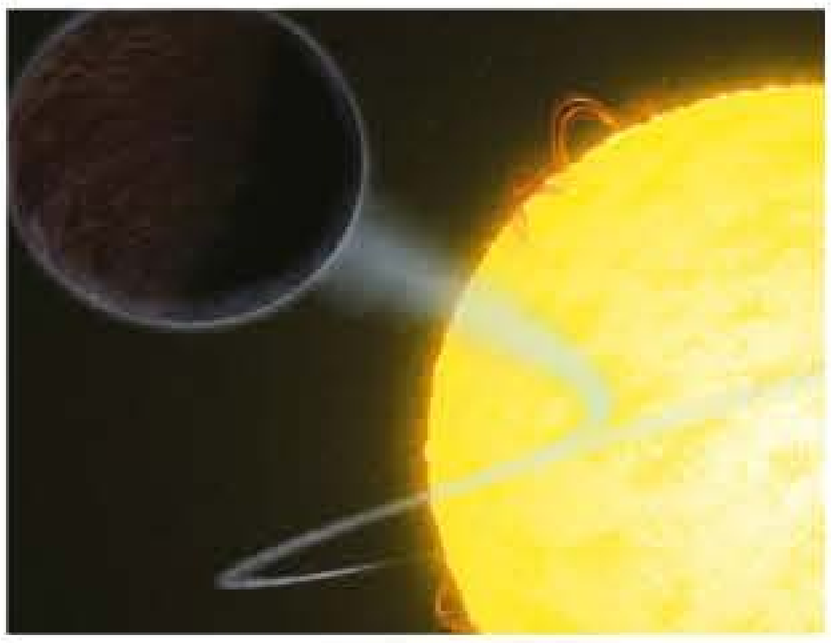
This type of exoplanet must lie in the host star's habitable zone, which is the region from the star where water can exist as a liquid. As this type of exoplanet would primarily have oceans of water on the surface, it would make for a enticing target of study.

Earth-like

This is the type of world astronomers are always desperate to find – the holy grail of exoplanets. An Earth analogue is an exoplanet that has physical and environmental conditions similar to Earth.

51 Pegasi b was the first exoplanet discovered orbiting a Sun-like star

The Kepler Space Telescope has uncovered a record-breaking number of exoplanets



WASP-12b absorbs around 94 per cent of its visible light, making it as black as fresh asphalt

> "This is unlike the atmosphere of any planet that we have observed so far" **Taylor Bell**

(near-UV) to visible light from about 290nm to 570nm," Nikolov explains to **All About Space**. "The spectra are then extracted, which means we have the exact dependence of the observed target brightness with wavelength."

From this they could obtain the spectra of the star and the planet during its transit, and also the 'spectral fingerprints' of the star alone as it eclipsed the planet in its orbit from our perspective on Earth. So by subtracting the spectra of the star alone from the spectra of the star and the planet, you thus receive the optical flux for the planet alone. "The surprise came when we actually got no difference in the measured flux [between star and planet]," says Nikolov.

"That simply means because there was no change, the planet reflects no visible light. The interpretation of this means that the planet is so black that if we illuminate it with a torch it wouldn't make any difference."

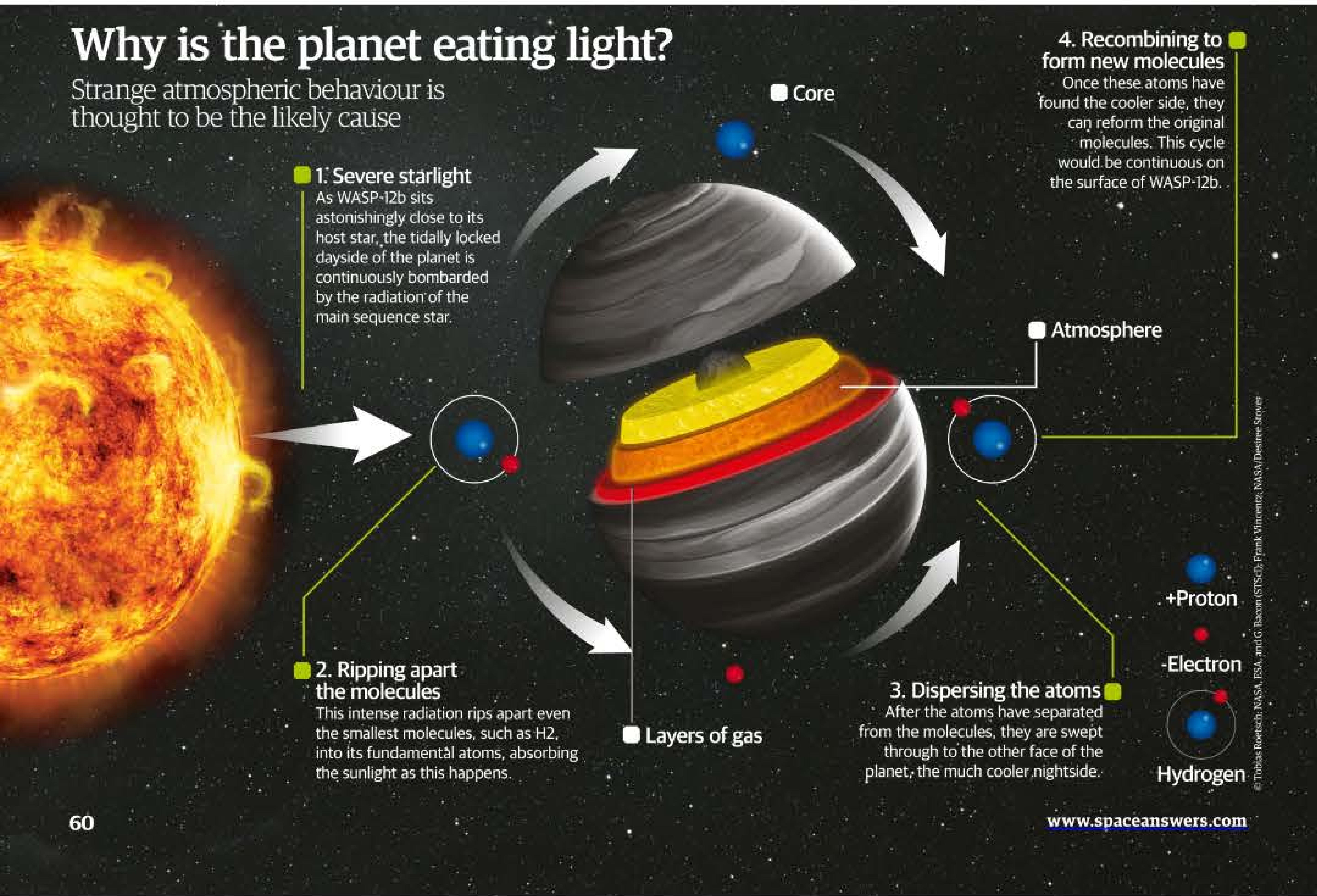
When asked about the reception regarding this discovery, Bell laughs, "The response has been quite positive. The public seems to have been quite intrigued by the findings and the associated imagery. There have been many confused people as well, some of which incorrectly think the planet could be a black hole, which it definitively is not."

It is extremely important to emphasise, the discovery has nothing to do with a black hole. A black hole is where the gravity of a celestial object is so intense, light literally cannot escape. What's happening in this case is that the exoplanet's atmosphere is absorbing the starlight rather than reflecting it, raising the blatant question: what is happening in the planet's atmosphere to cause this incredibly dark world?

The outstanding theory so far is that this gas giant's atmosphere is similar to the ones that wander our Solar System. So much like Jupiter and Saturn, WASP-12b is comprised of mostly hydrogen and helium - the two most abundant elements in the universe. But, because of the close orbit, the radiation from WASP-12 bombards the dayside of its gaseous planet, ripping apart even the lightest elements, such as hydrogen, into its constituent atoms. "This is unlike the atmosphere of any planet that we have observed so far - all planetary atmospheres we know of are mostly made of

Why is the planet eating light?

Strange atmospheric behaviour is thought to be the likely cause



1. Severe starlight
As WASP-12b sits astonishingly close to its host star, the tidally locked dayside of the planet is continuously bombarded by the radiation of the main sequence star.

2. Ripping apart the molecules
This intense radiation rips apart even the smallest molecules, such as H2, into its fundamental atoms, absorbing the sunlight as this happens.

3. Dispersing the atoms
After the atoms have separated from the molecules, they are swept through to the other face of the planet, the much cooler nightside.

4. Recombining to form new molecules
Once these atoms have found the cooler side, they can reform the original molecules. This cycle would be continuous on the surface of WASP-12b.

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molecules (mostly nitrogen and oxygen molecules here on Earth, or hydrogen molecules on planets as large as Jupiter)," explains Bell. "However, the atmospheres of stars are made mostly of atoms, which means that (assuming our model is correct) WASP-12b's dayside atmosphere is more like a stars atmosphere than a planets."

This is a particularly elusive suggestion; for a planet to have an atmosphere related to a star defies a large number of planetary models. However, when you introduce stellar modelling into the simulation, it can handle these processes of such unusual physics. From these models, Bell deciphered that atomic hydrogen - more specifically, the negative ion of atomic hydrogen - is quite opaque, which is most likely the cause for its low reflectivity. There is also the proposal that if sodium and/or potassium in the dayside atmosphere still have their electrons, this would also contribute to the pitch-black nature of the hot Jupiter.

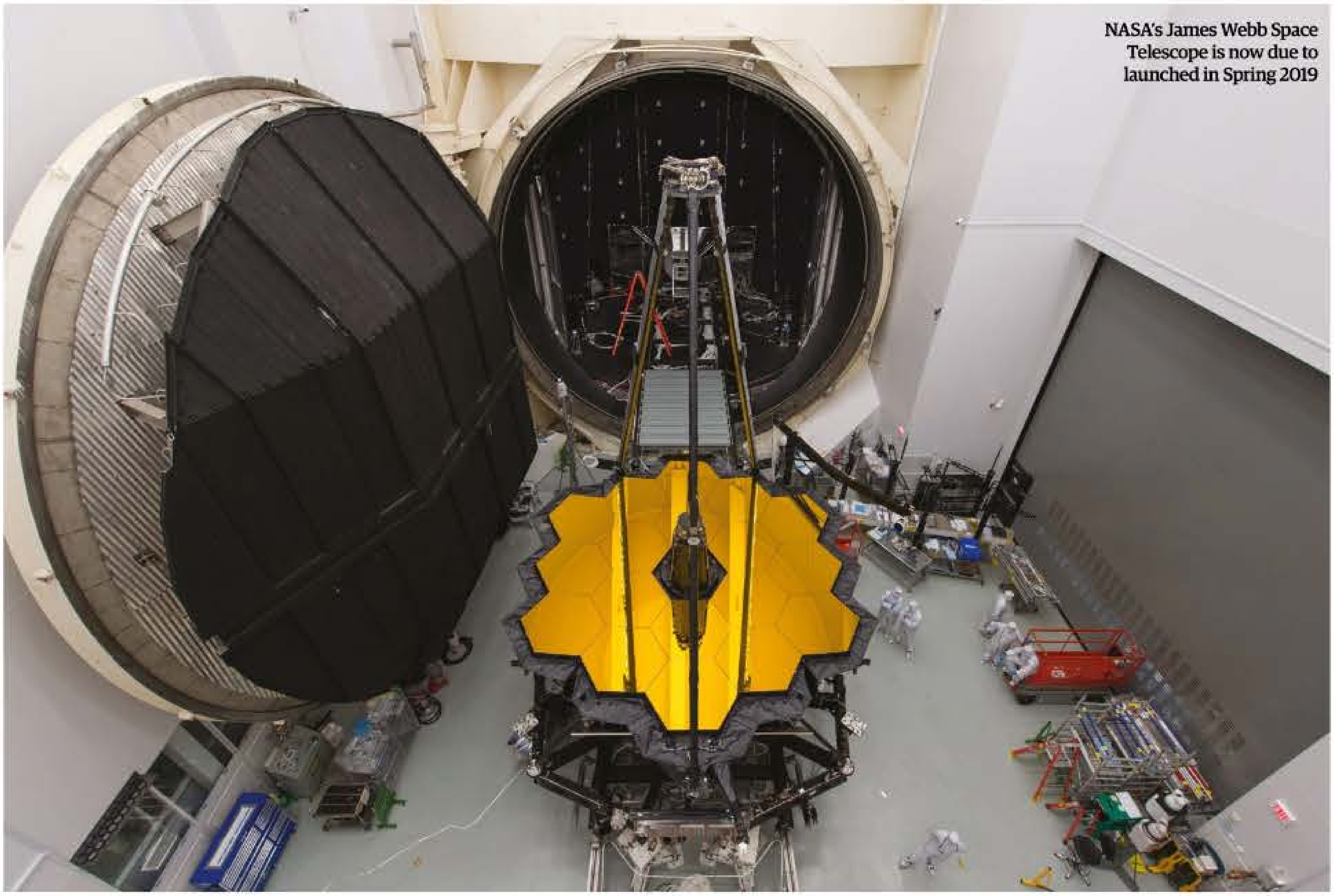
When the hydrogen molecules have been ripped apart by the intense heat on the dayside, it is then thought that they rejoin on the cooler nightside. This creates a cycle of hydrogen and helium molecules being dismantled on the dayside, swept over to the other face of the planet, and then unifying once more. But these are just theories - what is occurring in this strange, dark, world is yet to be fully understood. It is only with more specific and comprehensive models that will we be able to answer these questions. However, this can only happen when we understand the full spectrum of an ever-changing exoplanet world.

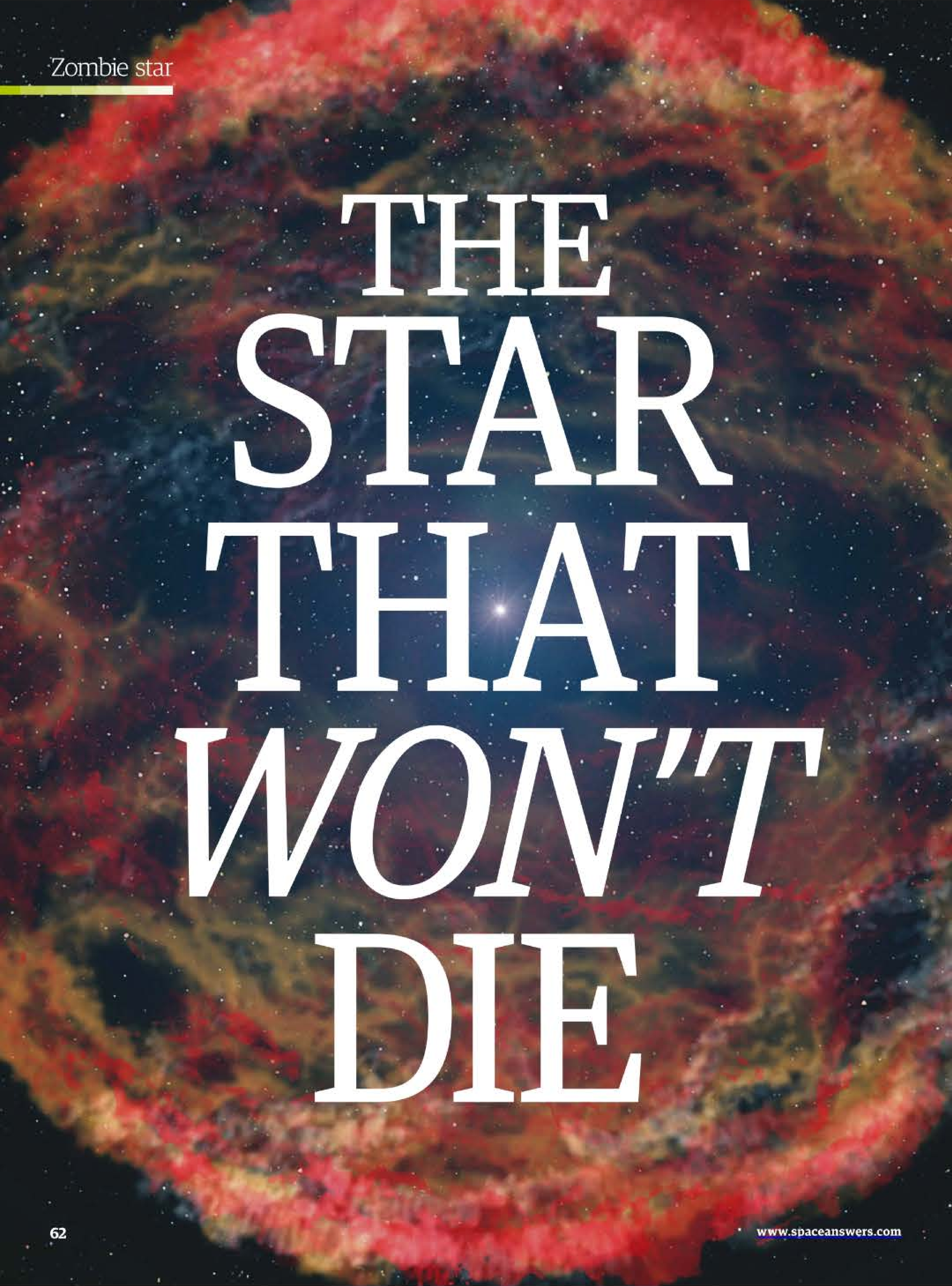
The Roque de los Muchachos Observatory is where the SuperWASP-North site is designated, and where WASP-12b was discovered

"This planet, along with other hot Jupiters, are important tools that allow us to test our understanding of atmospheres and atmospheric dynamics in conditions completely unlike those within our Solar System," says Bell. "By better understanding the processes occurring in these planets' atmospheres, we can hope to better understand atmospheres in general, whether they be around the Earth, a potentially habitable world or another star."

Nikolay described WASP-12b as a "benchmark for future studies" due to its unique characteristics. Future studies will have to wait though, as Bell and Nikolay both emphasise the need for NASA's James Webb Space Telescope (JWST) to conduct further measurements. The JWST will be able to study WASP-12b in mid-infrared, a currently inaccessible wavelength, which could prove vital for understanding the planet's unlit nature. With its 6.5-metre primary mirror, made up of 18 hexagonal mirrors coated with gold-plated beryllium metal, the JWST can observe WASP-12b in greater clarity.

Currently, the JWST has recently been pushed back from October 2018 to early 2019, due to unforeseen extra testing and delays involved in assembling this colossal space observatory. Yet, when it finally reaches space and turns it sights to WASP-12b, Bell and his team can continue their work in shedding light on this massive, mysterious and black planet.


NASA's James Webb Space Telescope is now due to launched in Spring 2019



THE STAR THAT *WON'T* DIE

Astronomers have encountered a star that continues to resurrect itself. But how is it coming back to life? **All About Space** meets the team with some head-turning answers

Written by Lee Cavendish

Iair Arcavi, an astronomer at Las Cumbres Observatory, led the discovery of the unusual star

Much like us humans, stars have a birth, a life and eventually, a dramatic end. Stars have a much more prolonged lifetime though, ranging from a few million years to trillions of years. The death of a star is dependant on its mass: it can either gently void its outer layers to form a planetary nebula or blow itself apart in a magnificent explosion called a supernova. For a regular star, a supernova is a one-off event, marking the end of a star's proactive life - or, at least that's what we thought.

Astronomers have found a star that has appeared to go through multiple supernovae in a space of over 60 years. This astronomical enigma challenges our understanding of supernovae, and the nature of massive stars. There are two common types of supernova: Type Ia and Type II supernova. Firstly, a Type Ia supernova commonly occurs in a pair of stars gravitationally bound together, known in astronomy as a binary star system. In this case, one of the stars must be a white dwarf star - a very dense and small stellar core remnant - and its companion can either be a giant star or an even smaller white dwarf. As the stellar dwarf begins to consume the contents of its partner, it will eventually reach 1.4-times the mass of our Sun, known as the Chandrasekhar Limit. This forces the white dwarf into a state of instability, thus dying in an extravagant, bright explosion known as a Type Ia supernova.

A supernova doesn't just occur in a white dwarf binary star system though. It can also occur to some of the most massive lone stars in the universe with masses of at least eight-times our Sun's. When these stars reach the end of their life, the hydrogen and eventually helium, powering the star's core will begin to be converted into higher-mass elements in order to keep its engine running. From helium, carbon is made, then oxygen, then neon, then magnesium, then silicon, until iron is produced in its core. At this point, the star requires energy to convert iron into a heavier element, rather than radiate energy. This is the final hurrah for the star, as it can no longer produce sufficient energy to counteract the cooling core and it eventually collapses under its own mass. This causes an implosion within the star, which bounces off the iron core and disperses its outer layers. This event is referred to as a Type II supernova; it sends copious amounts of gas into the cosmos, where it is recycled for future stars, planets and anything else which may lie out there.

> "This discovery has made astronomers question the very nature of supernovae and consider new explanations"

These two types of supernovae would appear indistinguishable to the naked eye, as they'd just appear to be spectacular explosions that scatter gas and dust throughout the universe. However, there are subtle differences between the two types that are revealed by the supernova's spectrum, which shows the intensity of light across a range of wavelengths. When an element is present in the gas and dust, it will absorb energy at a specific wavelength, and astronomers can identify this by studying the chemical fingerprint that is its spectrum.

There is also the characterisation of its brightness fading over time. When the commencing explosion lights up the sky, astronomers worldwide turn their telescopes to the scene of the crime to observe the afterglow. Astronomers construct a graph to see how the

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brightness of the star changes over an extended period of time, also known as a lightcurve. It is the shape of the lightcurve that helps astronomers determine what type of supernova occurred.

If you're looking at the lightcurve of a Type Ia supernova, the two most distinguishable features are the sharp increase in brightness, reaching up to five-billion-times the luminosity of our Sun, followed by a gradual decline. When compared to the lightcurve of a Type II supernova, the Type II has a similar sharp initial increase in brightness, but there tends to be a period of no luminosity change after its explosion, followed by a dimming lasting approximately 100 days. When comparing the spectra of the two supernovae there is actually just one simple question to ask when differentiating the two: are there hydrogen absorption lines? If the answer is yes, then you have a Type II supernova. If they are not present, you have a Type Ia supernova.

In February 2013, the California Institute of Technology (Caltech)-led intermediate Palomar Transient Factory (iPTF) project started its search for supernovae, among other transient objects, exploding in the night sky from the Palomar Observatory in San Diego, California, US. "iPTF was very successful in finding supernova - so successful, in fact, that it was finding about ten supernovae every night," Iair Arcavi, NASA Einstein Fellow at the University of California, Santa Barbara and formerly of the Las Cumbres Observatory Global Telescope (LCOGT), tells All About Space. "This is more than we can follow, so we had to choose which ones we thought were interesting and which ones we let go."

Then, in September 2014, the project identified one supernova that originally didn't provoke much of a reaction. "iPTF14hls was one of those we initially let go because when it was discovered, it was getting faint. So we thought it was just an old supernova [that had] passed its peak luminosity," continues Arcavi. "However, iPTF continued to image that part of the sky for its survey, so we were able to see what iPTF14hls was doing for the next few months.

"In February [2015], an intern working for me, Zheng (Andrew) Wong, noticed that iPTF14hls started to get bright again. He asked me whether that was normal, and I said absolutely not, a supernova almost never gets brighter again after having faded." What the LCOGT team had originally classified as a Type II-P supernova, based on its spectra and the plateau in its lightcurve, seemed to be coming back to life.

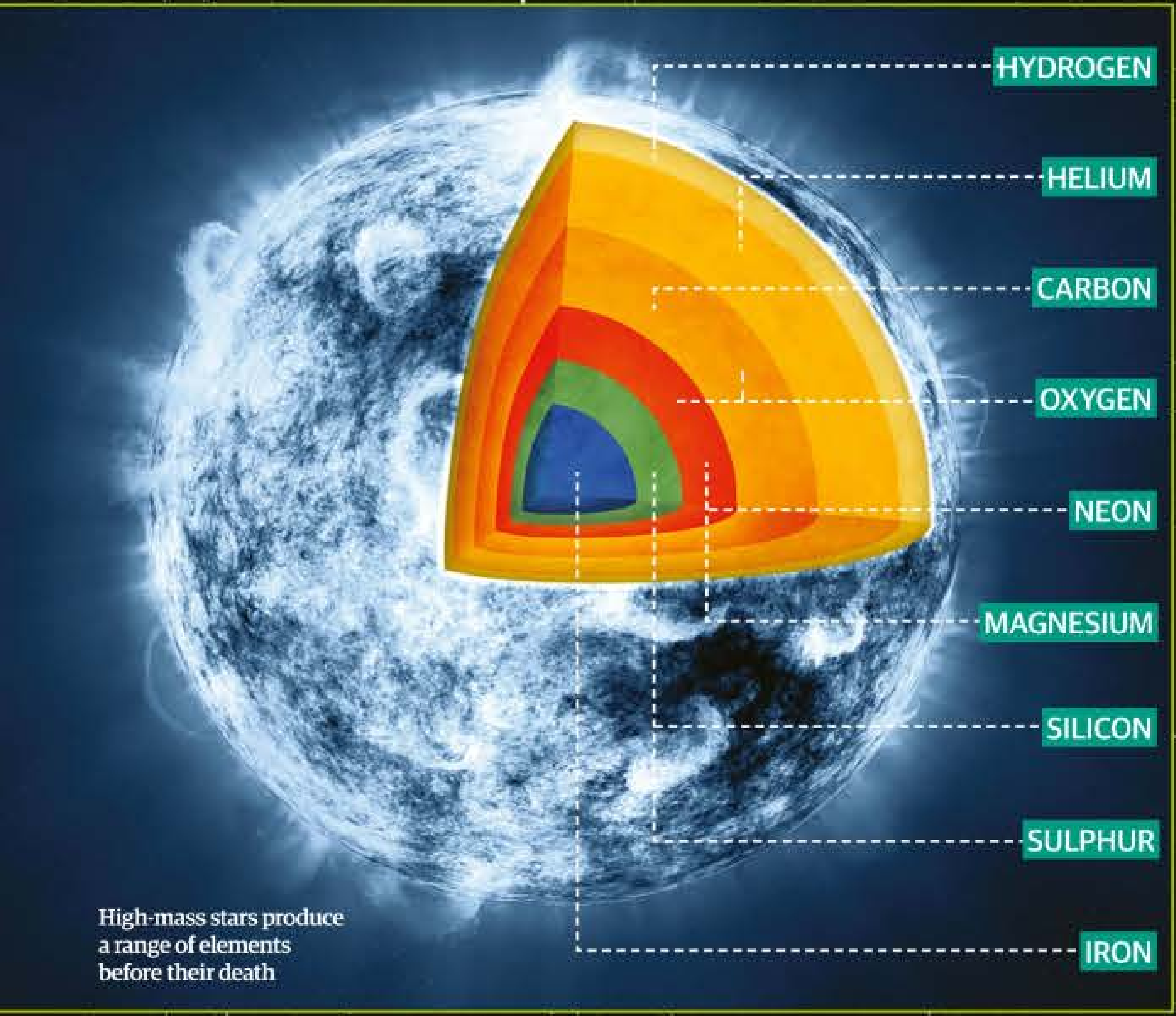
This 'zombie star' iPTF14hls, located over half-a-billion-light-years away in the constellation of Ursa Major (The Great Bear), proved to be quite the conundrum across the scientific community. This mysterious stellar phenomenon surpassed the typical 100-day lightcurve; instead it displayed an astonishing five peaks over the next 600 days under around-the-clock observations, and also appears to age ten-times slower than expected. This discovery has made astronomers question the very nature of supernovae and consider new explanations for such an event. Andy Howell, leader of the supernova team at LCOGT, described iPTF14hls as "a problem for our standard theories of supernovae. When that happens, it forces us to get creative." This called for further investigation, along with much creativity.

Unfortunately, astronomers couldn't pin down a proper explanation for such an event. If a theory was suggested to explain its erratic behaviour, there was always a new piece of data ready to disprove it. "With each new piece of data we got, the supernova kept getting weirder and weirder," Howell explains. "We initially had some theories that we thought could explain the data, but then we'd get new data that would refute those theories."

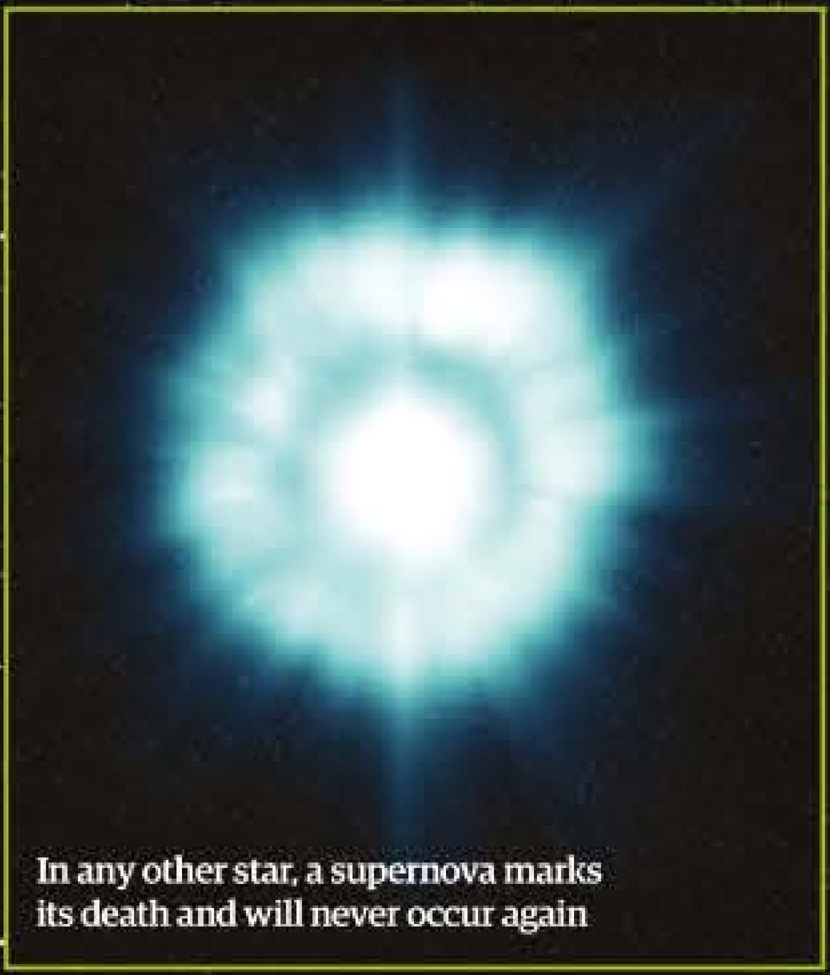
To make matters even more interesting, the researchers that were already working hard to decipher what they could from the observations of the perpetual star delved deeper into the archives. As it turns out, there was a recorded explosion at the exact same position in 1954. Although there is still some doubt whether this is the case, there is an extremely strong likelihood that it is the same star. Therefore, this star has been producing explosion after explosion for over 60 years - and has miraculously survived each time.

To power such an ancient engine, there's got to be a lot of fuel in the tank, thus expelling copious amounts of hydrogen in the process. Arcavi, Howell and their colleagues have estimated that hydrogen gas roughly 50-times the mass of the Sun has been ejected from the star alone. With this level of mass

> "With each new piece of data we got, the supernova kept getting weirder and weirder" **Andy Howell**



High-mass stars produce a range of elements before their death

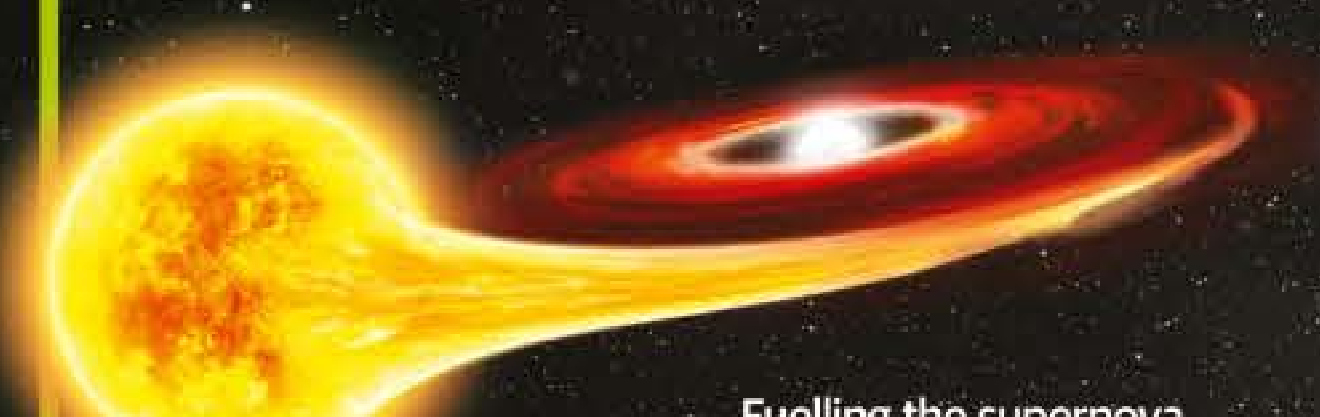


In any other star, a supernova marks its death and will never occur again

The universe's exploding stars

There are two common types of supernovae: Type Ia and II. However, iPTF14hls seems to defy our understanding of supernovae, so astronomers have had to come up with a new explanation

Type Ia supernova



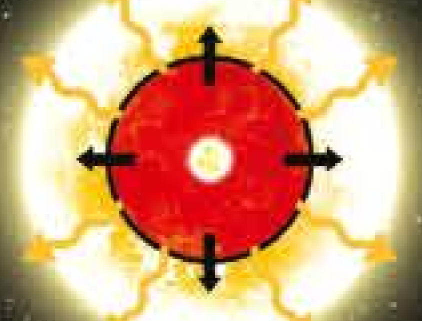
Fuelling the supernova
Here, the red supergiant swells due to increased radiation pressure, the white dwarf begins to consume its companion's outer layers.

Increasing instability
The white dwarf will continue to strip the material off the red supergiant, becoming more and more unstable as it does.

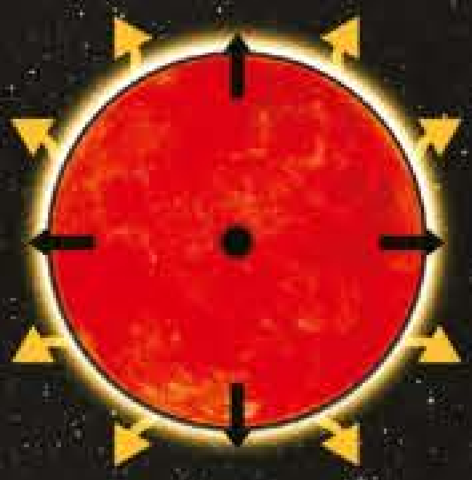
The grand finale
When the white dwarf reaches 1.4-times the mass of the Sun, it reaches the point of no return and explodes as a Type Ia supernova.

Type II supernova

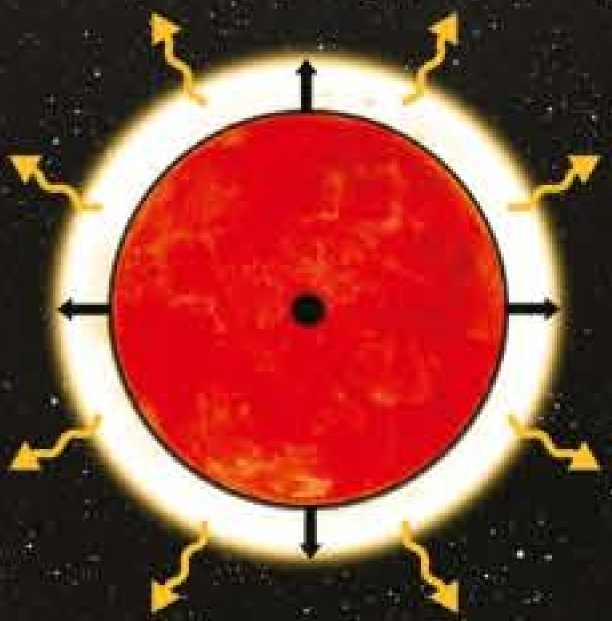
Creating the medley of metals
The massive star will create layers of heavier elements in the core, until it reaches iron. This will spark the beginning of the end.



Star out of equilibrium
As the core can no longer produce sufficient energy to balance out the gravitational pressure of the star's own mass, it is essentially doomed.

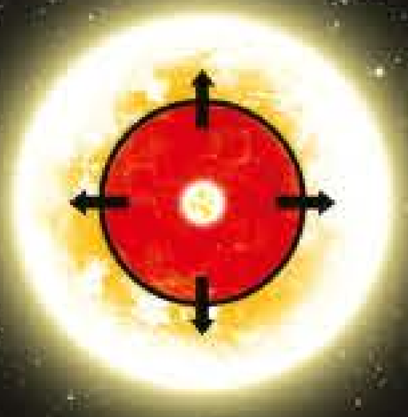


Crushing under force
The gravity of the star crushes and condenses the star; this creates incredible pressures in the centre of the star. This leads to an implosion within the star.

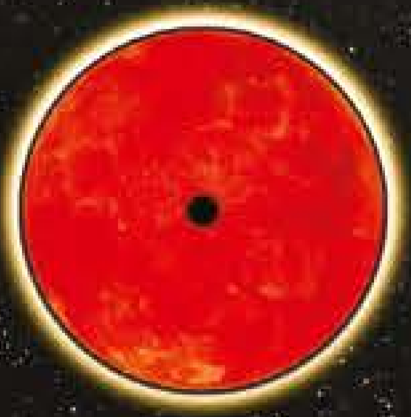


Implosion then explosion
This implosion causes the star's inner layers to bounce off the dense iron core, thus creating the spectacular Type II supernova explosion.

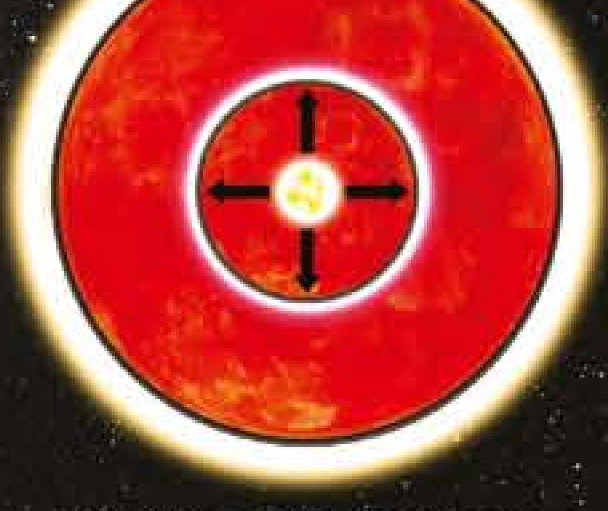
The star that won't die



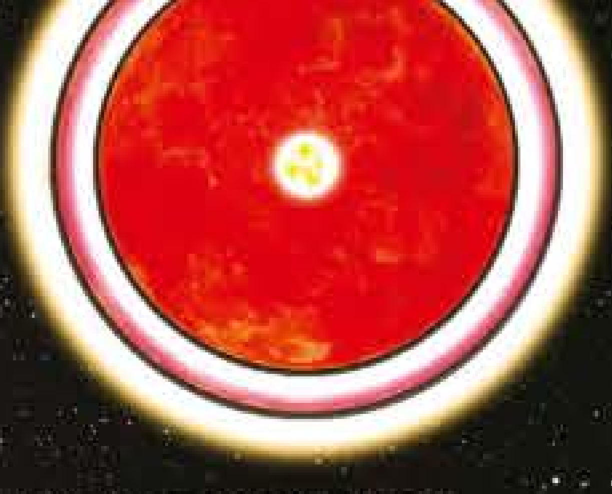
Shells surrounding the massive star
Prior to the supernova, shells of gas are thought to be surrounding the star, most probably swept out by the star's stellar winds.



The initial explosion
The instigating Type II supernova then occurred. This category of supernova correlates with the spectra analysed by the astronomers.



Colliding with the layers
The shock wave sent the star's outer layers travelling at thousands of kilometres per second, encountering shells of slower-moving material on its travels.



Changes in brightness
Each encounter with a shell of material would cause the continuous luminosity increase, and the kinetic energy created would be converted into light.

© NASA; Tobias Roetsch; ESA/ECF

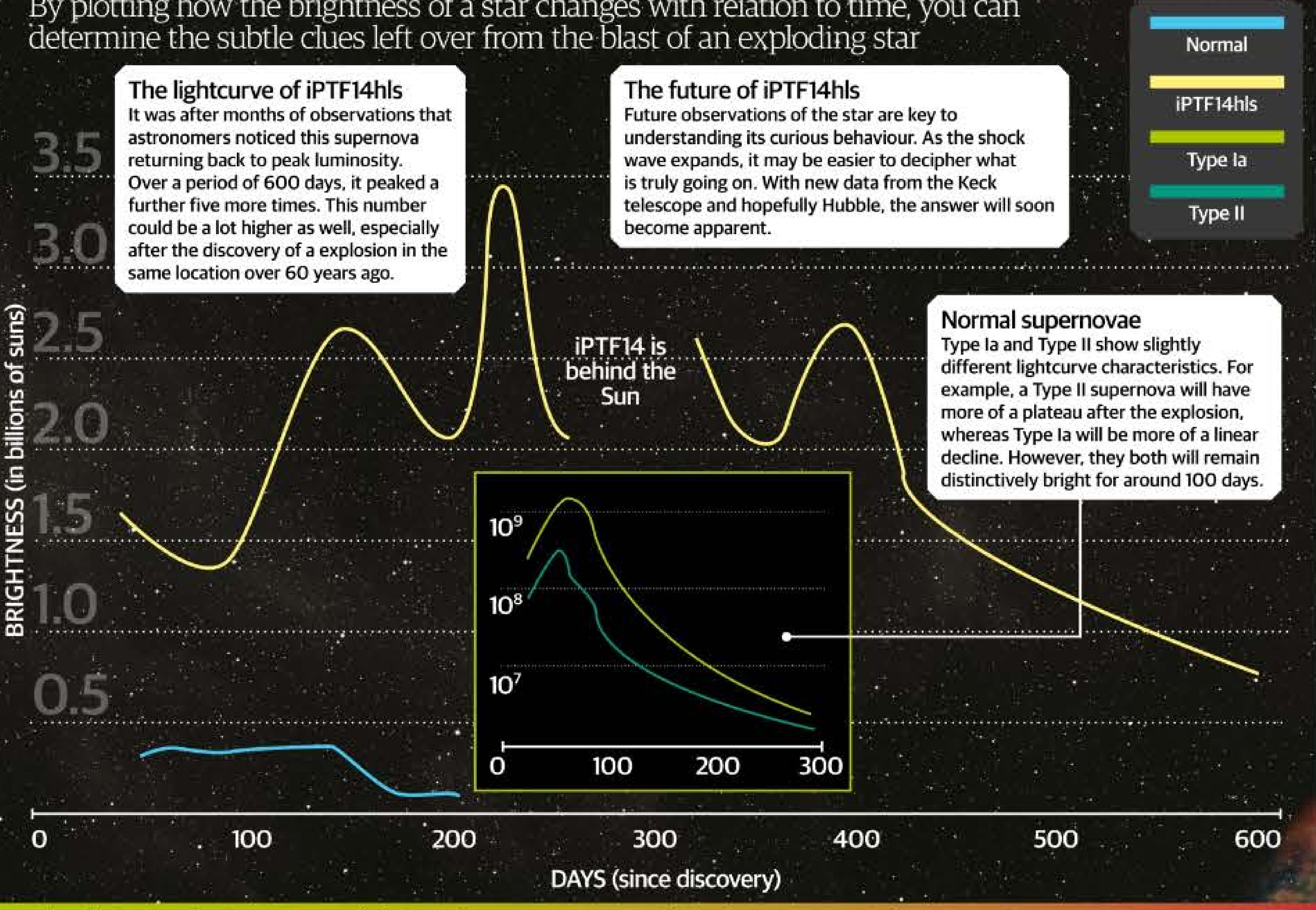
Arcavi hopes to use the Hubble Space Telescope to look closer at the stellar neighbourhood

being thrown out into the cosmos, the original mass of iPTF14hls would have been enormous. Because of this, Arcavi again estimates that this star would have been at least 100-times the mass of our Sun. To put that into further context, that is over 300-million-times bigger than the Earth. Arcavi even made a point to say "this could be the most massive star we've ever seen explode".

These types of massive stars are the most volatile and dramatic stars in the universe and follow the rock-and-roll lifestyle of 'living fast and dying young'. Although these stars will only live for a few million years – which is young in cosmic standards – what they do in terms of supplying the universe with energy and material is vital. As mentioned previously, these massive stars create elements from helium to iron before these are cast off into the universe via a spectacular supernova. As human beings, we are made up of these elements. Hydrogen and oxygen formulate water, which makes up around 60 per cent of an adult's body. Iron is needed in our red blood cells to carry oxygen to our muscles and revitalise them. Carbon is the basic building block of proteins, carbohydrates and fats, among others. These

What do lightcurves say about the supernova?

By plotting how the brightness of a star changes with relation to time, you can determine the subtle clues left over from the blast of an exploding star



The lightcurve of iPTF14hls

It was after months of observations that astronomers noticed this supernova returning back to peak luminosity. Over a period of 600 days, it peaked a further five more times. This number could be a lot higher as well, especially after the discovery of a explosion in the same location over 60 years ago.

The future of iPTF14hls

Future observations of the star are key to understanding its curious behaviour. As the shock wave expands, it may be easier to decipher what is truly going on. With new data from the Keck telescope and hopefully Hubble, the answer will soon become apparent.

Normal supernovae

Type Ia and Type II show slightly different lightcurve characteristics. For example, a Type II supernova will have more of a plateau after the explosion, whereas Type Ia will be more of a linear decline. However, they both will remain distinctively bright for around 100 days.

elements makes us who we are, and they originate from the death of these stellar giants.

However, understanding what is happening to the star is a lot more complicated. When asked what is happening to the star for this to occur, Arcavi replied, "The short answer is that we don't know. iPTF14hls breaks all the theoretical models of supernova behaviour that we have." However, there are some possibilities floating around that explain some of these elusive aspects.

"I think we may be converging on an explanation that involves a supernova running into shells of matter around it," Stan Woosley, director of the Center for Supernova Research at the University of California, Santa Cruz, tells All About Space. "The [time] duration [of the peak luminosity] is how long it takes the expanding supernova to pass through those shells, not how long it took the supernova to initially explode." The star prior to the explosion could have blown off these previously existing shells of material surrounding the progenitor star, possibly by stellar winds.

After the initial supernova sent material soaring off in all directions travelling at thousands of kilometres per second, it's thought it eventually went crashing into a slower-moving shell. This collision is what produced the kinetic energy being converted into light that travelled 500-million-light-years through the cosmos to be picked up by the iPTF telescope. It is thought this shock wave encountered many layers like this, creating the five peaks between Sepetmber 2014 and May 2015.

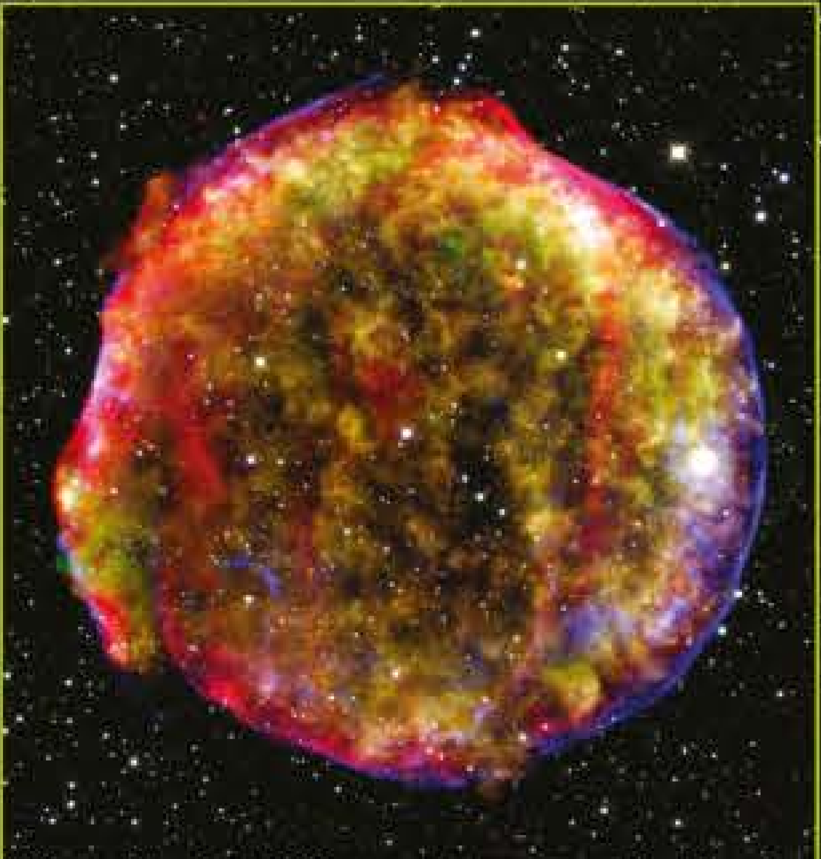
However, science is never that easy, and there are always issues. Although his theory explains the shape of iPTF14hls' lightcurve, it doesn't explain the full nature of the spectra collected. From first glance, the spectra of the star's light resembled that of a hydrogen-rich Type II supernova, which has prominent signs of hydrogen absorption lines. Counterintuitive to the point, there was no sign of the slower-moving material. Common sense would say that if there's material standing in the way of a shock wave, there should be a sign of it in the star's spectral fingerprint.

After the news of this undying star hit the headlines, many astronomers joined the search for a true answer. Roughly a month later, Jennifer Andrews and Nathan Smith of the Steward Observatory, University of Arizona, submitted a theory suggesting the supernova collided with dense circumstellar material (CSM), producing the influx of light while simultaneously masking it. While this masking effect - caused by the supernova ejecta - would hide all spectral signs of the CSM, there would also be a clear signature left from the interaction between the two.

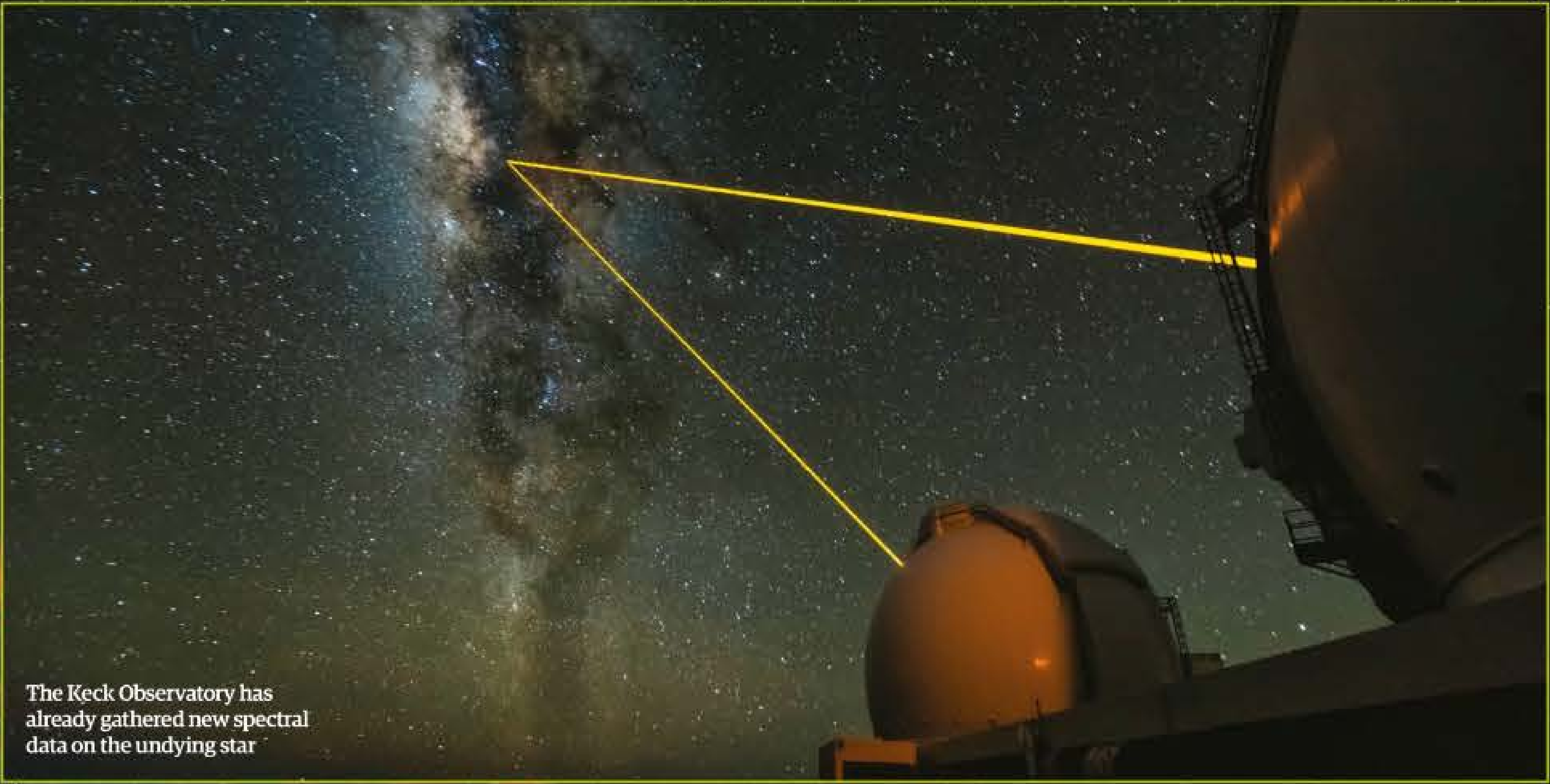
The one thing that is clear is that there is much more work needed to be done. Arcavi hopes that the flower continues to blossom, revealing the instigator of this peculiarity: "The supernova is still shining. As the material from the explosion expands, it gets easier to see inside. However, the supernova is also fading. So we're hoping to be able to get some new clues from the inner parts of the explosion that are now being revealed before it gets too faint to detect."

So, the countdown is on. This dedicated team of astronomers continue to get as much information as they can on its decline. Since its discovery, there has been new spectrum data collected by the W. M. Keck Observatory, Mauna Kea, Hawaii. There are also plans to use the Hubble Space Telescope and take advantage of its incredible high-resolution power. Until then, these astronomers will continue to scratch their heads as they try and unravel the mystery of the star that just refuses to stop shining.

A supernova can reach the luminosity equivalent to billions of our Sun's luminosity



Elements ejected from a supernova replenish the interstellar medium



The Keck Observatory has already gathered new spectral data on the undying star

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Future Tech

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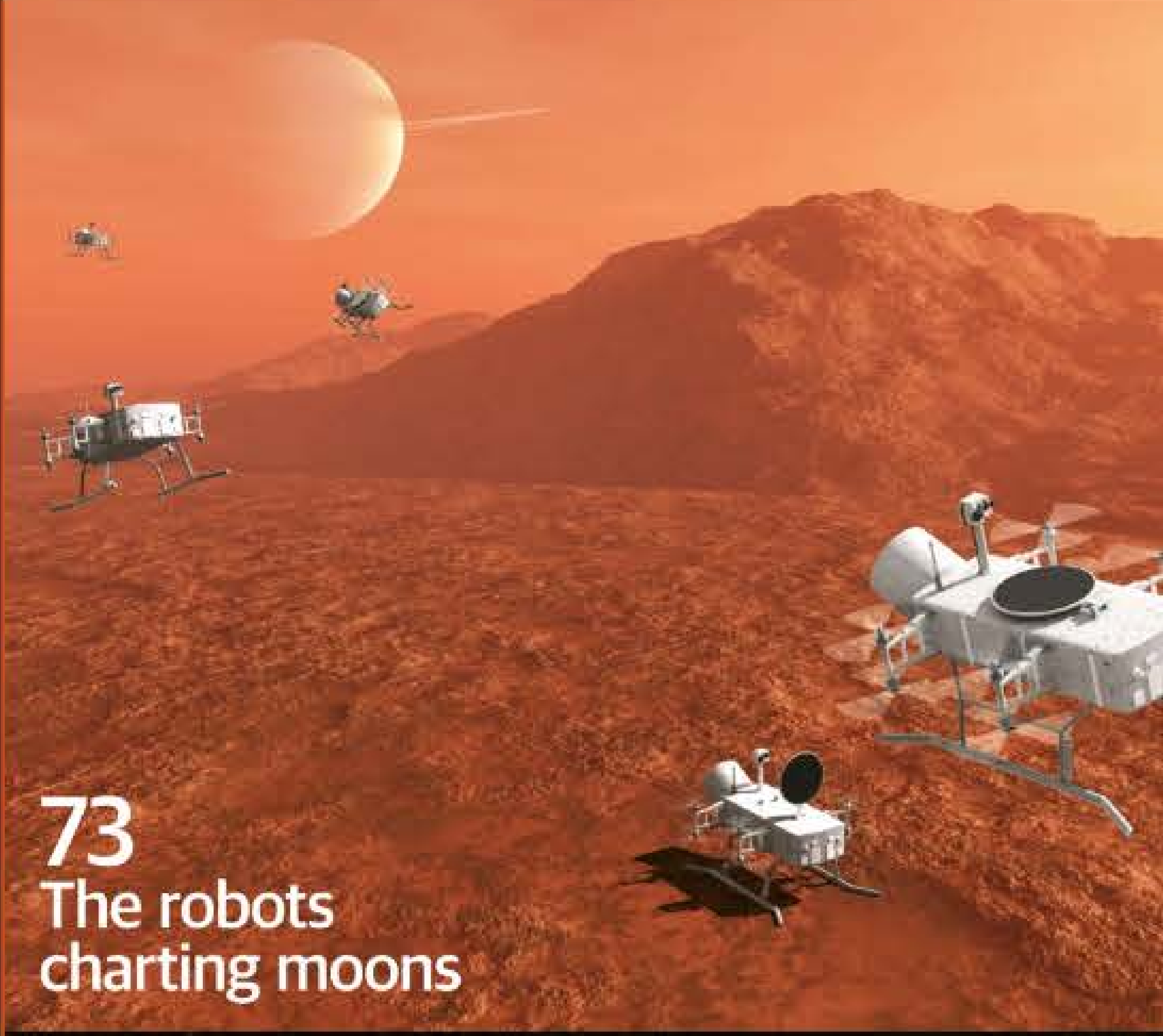
Humanity's best chance of reaching other star systems could be flying colonies that would spend centuries in transit

“Perhaps larger than the technical challenges are the ethical ones”



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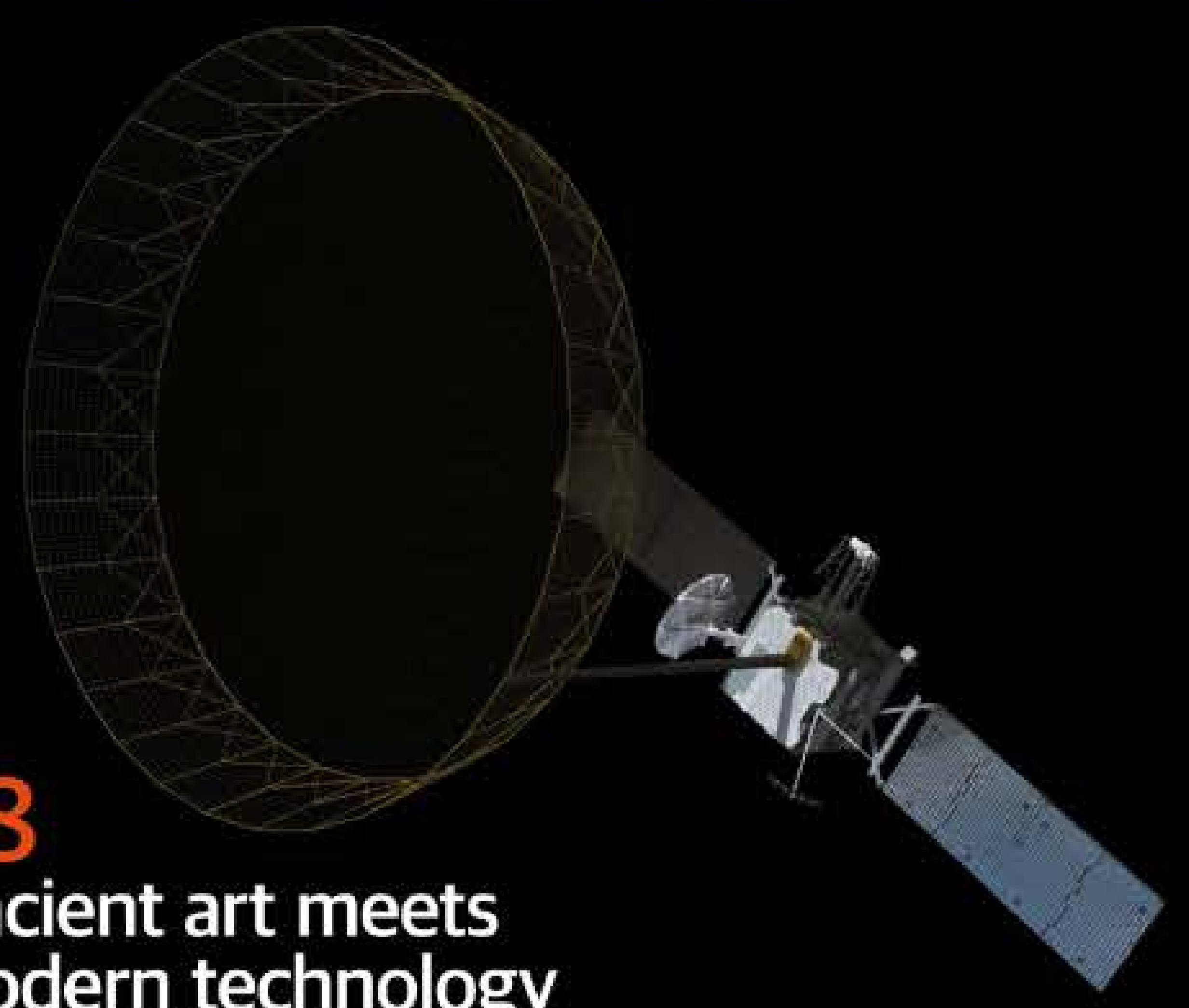


78
Ancient art meets modern technology

Obliterating space junk with a laser cannon

The Russian space agency has recently announced plans to turn a three-metre optical telescope into a debris destroyer

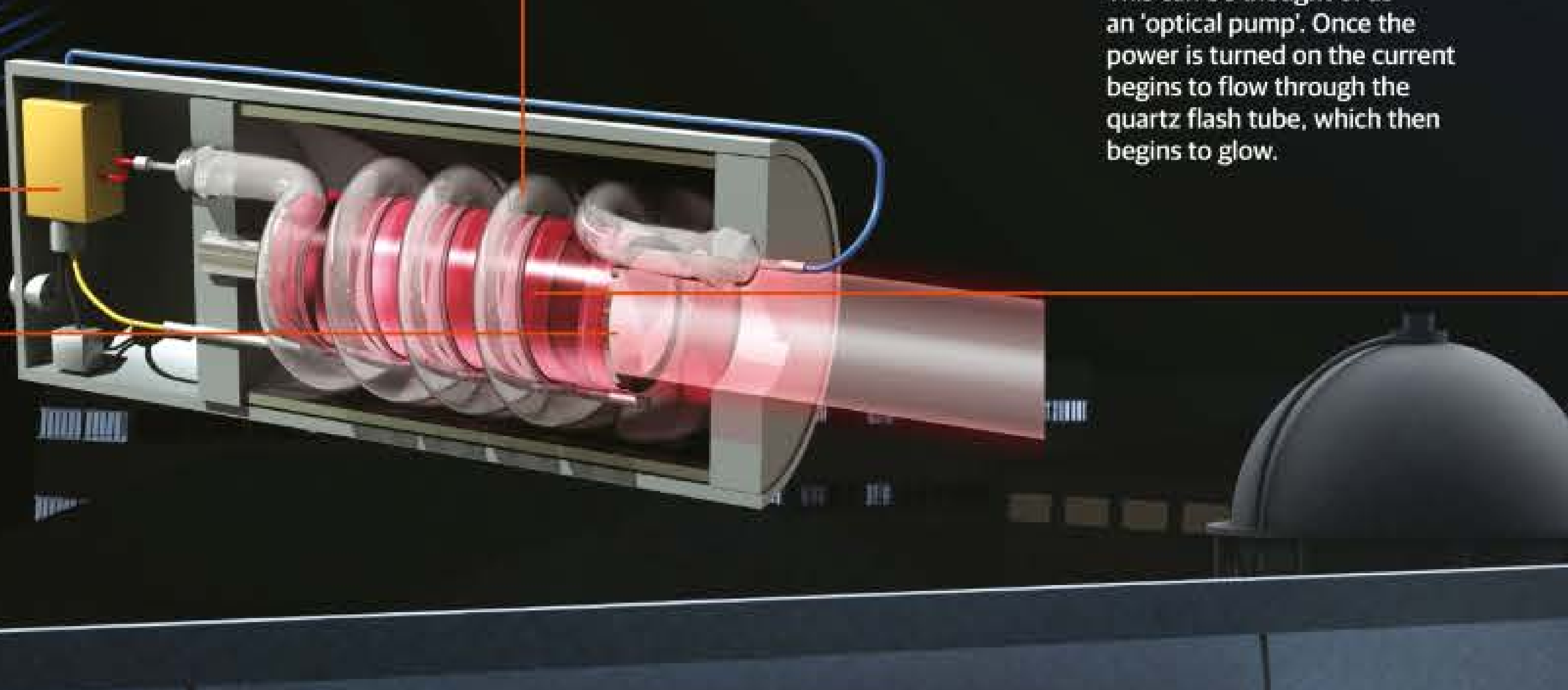
It's not quite the calibre of the Death Star from *Star Wars*, but Russian space agency Roscosmos is planning to build a laser cannon that will clean up low-Earth orbit, one piece of space junk at a time. Scientists at the Research-and-Production Corporation Precision Systems, which is a subdivision of Roscosmos, aim to attach a giant laser cannon on to a three-metre optical telescope. This laser cannon would have a carefully designed mechanism attached to the telescope, which utilises a series of reflective mirrors, a quartz flash tube and a solid-base generator power supply to create a laser beam powerful enough to evaporate pieces of metal floating around in space.

This telescope is already under development, and its main purpose is to monitor satellites and any potentially dangerous pieces of space junk floating between 160 to 2,000 kilometres (100 to 1,242 miles) above the Earth's surface. NASA estimates that there are over 500,000 pieces of space junk that are marble-sized or larger in low-Earth orbit, and they can reach speeds of up to 28,164 kilometres (17,500 miles) per hour. These pieces of junk are left over debris from obsolete satellites, space stations or fragments from space collisions. With the International Space Station (ISS) and even more satellites being put into low-Earth Orbit, these pieces of junk can pose a major threat. They could also potentially break through the atmosphere and find their way to the ground, proving to be a potential hazard to us.

Previous events emphasise the dangers of space debris, including the Kosmos-954 incident in January 1978, when the former Soviet reconnaissance satellite reentered the Earth's atmosphere over Canada; in doing so it broke up into smaller pieces and deposited radioactive material over some 124,000 square kilometres (47,877 square miles) of land. Also, in April 2016, a chip in one of the ISS' glass panels was thought to be caused by the impact of a tiny piece of space debris - possibly a paint flake or a tiny metal fragment. If it wasn't for the quadruple-glazed glass, there could have been a serious problem.

For these reasons, the issue of space junk and its disposal has become more important to organisations such as NASA, ESA and Roscosmos. Previous suggestions to remove space junk have included a massive space-net and solar sails to push the debris out of its current orbit. The idea of a 'giant laser cannon' is an interesting concept, as it would require a solid-base generator attachment among other instrument concepts to bring this science-fiction idea into reality.

The intensified light would bounce off the mirrors of the telescope until a powerful laser beam is created, which can remove space debris through a process called 'laser ablation'. This is commonly used to remove layers of material from metals or industrial compounds. However, in the case of this new technology, this laser beam would be able to heat space debris up to temperatures where it would evaporate and be obliterated.

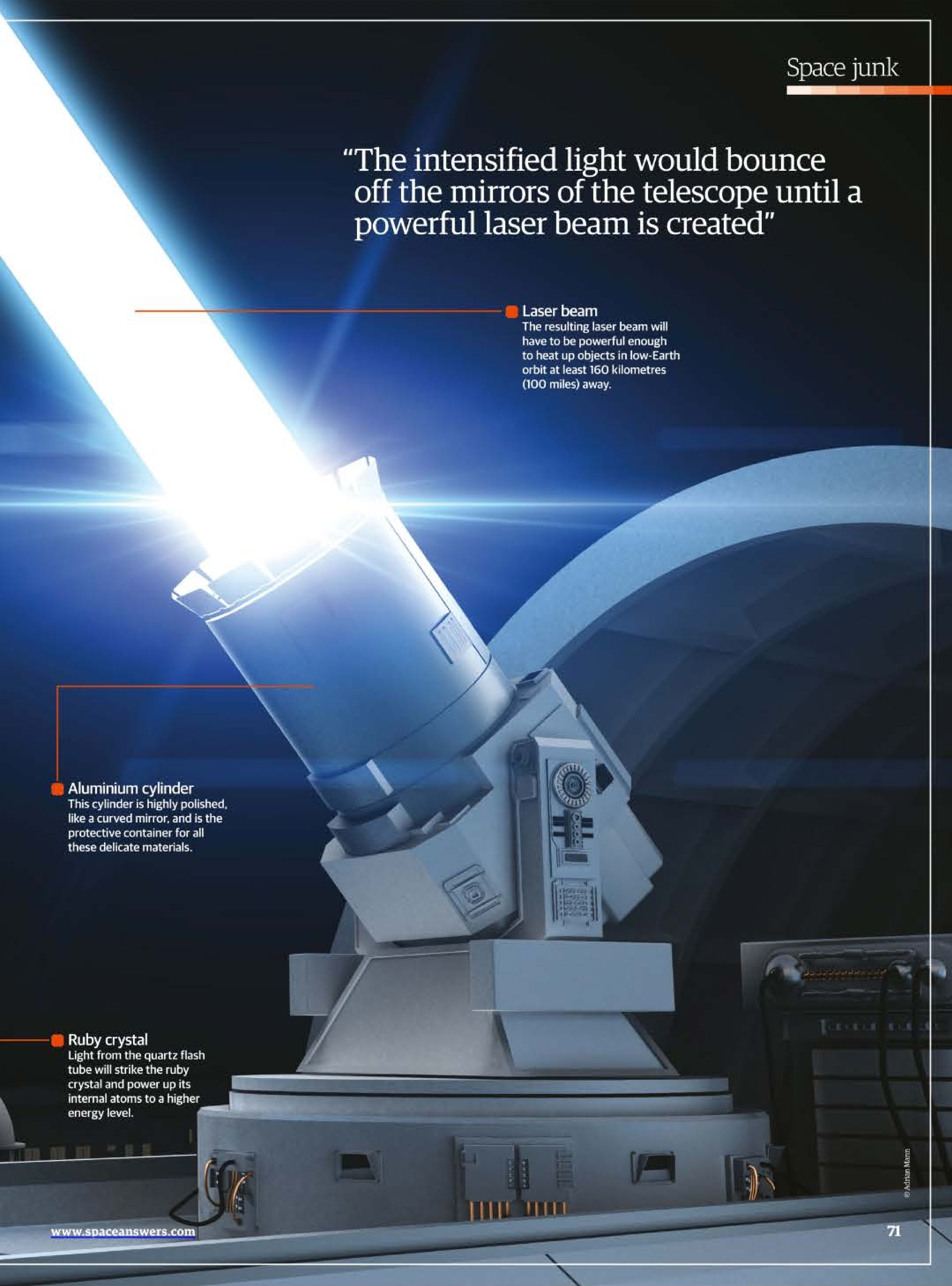


Power supply
This solid-base generator will excite electrons. This will emit the light waves that constitute laser beams before being concentrated through the mirrors and flash tube.

Quartz flash tube
This can be thought of as an 'optical pump'. Once the power is turned on the current begins to flow through the quartz flash tube, which then begins to glow.

Reflective mirror
Using a series of mirrors with different percentages of reflectivity, the excited photons of light are thrown back into the quartz flash tube, amplifying the light into a laser beam.

“The intensified light would bounce off the mirrors of the telescope until a powerful laser beam is created”



Laser beam
The resulting laser beam will have to be powerful enough to heat up objects in low-Earth orbit at least 160 kilometres (100 miles) away.

Aluminium cylinder
This cylinder is highly polished, like a curved mirror, and is the protective container for all these delicate materials.

Ruby crystal
Light from the quartz flash tube will strike the ruby crystal and power up its internal atoms to a higher energy level.

© Adrian Mann

Nuclear power
There isn't enough solar energy available on Titan to power such an energy-intensive mission as Dragonfly, so it will use a Multi-Mission Radioisotope Thermoelectric Generator powered by plutonium.

Thick atmosphere
The atmosphere is denser than Earth being mostly nitrogen (95%) and methane (5%) as well as other small amounts of carbon-rich compounds.

Titan quadcopter

NASA's innovative proposal to send a robotic dragonfly to scout Saturn's largest moon

One of NASA's most impressive current projects is the Curiosity Mars rover. The 899-kilogram (1981-pound) nuclear-powered rover is a travelling laboratory, which was landed on the Red Planet's surface by a rocket-powered sky crane in 2012. However, it is no simple matter to navigate a $2.5 billion rover on another world. As a result, the Curiosity rover moves very cautiously, crawling along at up to 200 metres (656 feet) per day, travelling 17.81 kilometres (11.06 miles) as of sol 1891, which equates to around five Earth years. This inevitably limits the reach of such missions, and will be even more challenging on our next landing targets - the large moons of Jupiter and Saturn. The most interesting of these moons, Saturn's Titan, offers an unique opportunity in the Solar System.

Titan is among one of the most Earth-like worlds in our Solar System; it may be cold, but like Earth, and unlike any other moon, it has a thick atmosphere and a rocky surface. In principle, you'd only need an oxygen mask and very warm clothes to survive. Titan's atmosphere is mainly composed of nitrogen, creating an atmospheric pressure of almost 1.5 times greater than our planet. The surface density is four times greater but the surface gravity is only 1/7th of the Earth's; this combination makes it much easier to perform aerodynamic flight. It is even theorised that human visitors might be able to fly with arm-mounted wings! Titan's atmosphere is also what makes the moon such an important target for exploration: the temperature and pressure are such that a mixture of hydrocarbon liquid exists as water does on Earth. This forms lakes, seas, clouds and snow, if it's cold enough. Simulations suggest Titan's rainfall will consist of very large drops falling in slow motion!

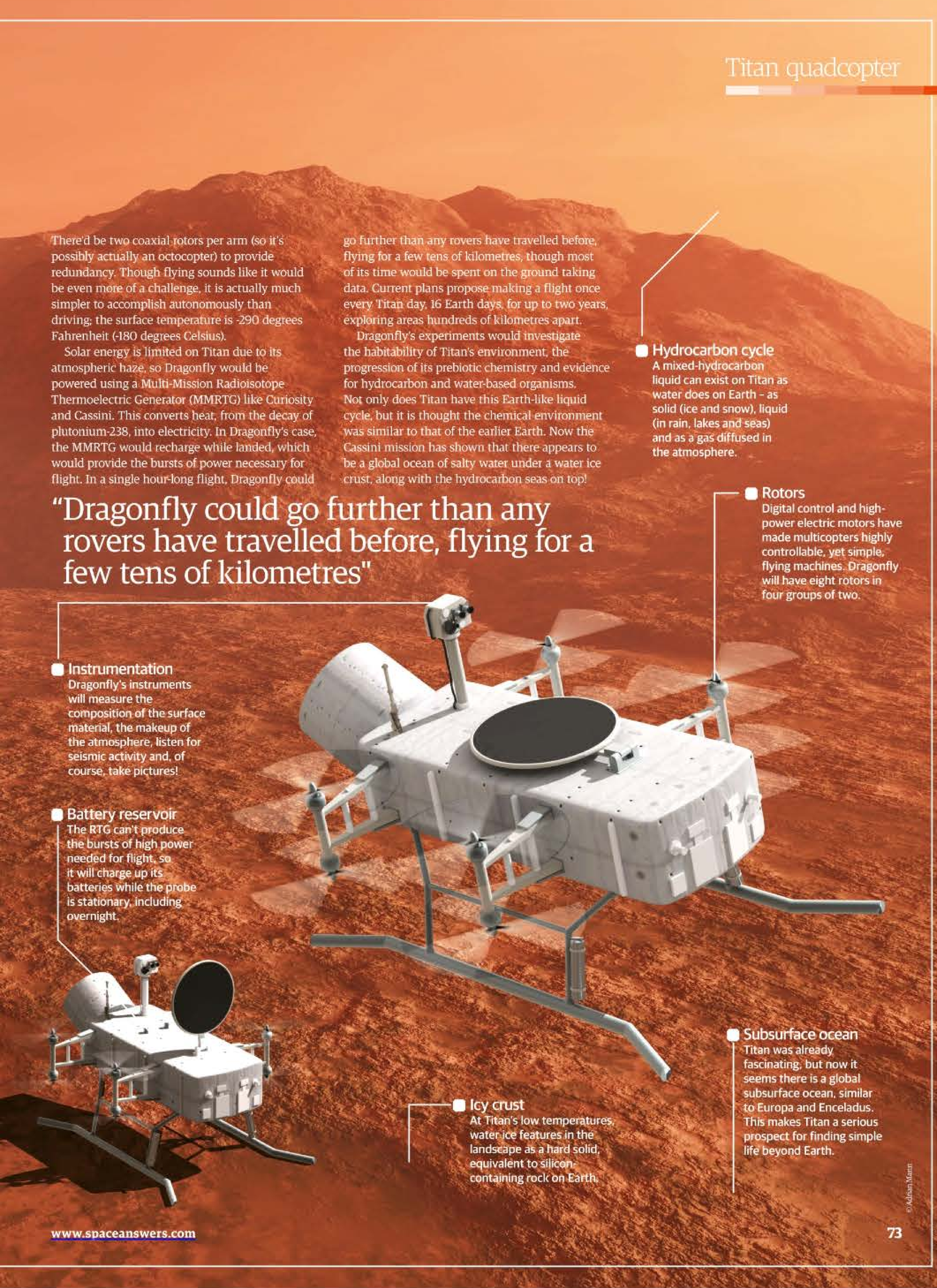
As part of NASA's New Frontiers program, this mission aims to exploit Titan's aeronautical advantages by sending a dual-quadcopter drone. The Dragonfly lander has been proposed by The Johns Hopkins Applied Physics Laboratory in Maryland, and would be much like a traditional lander, but equipped with rotors on four arms.

There'd be two coaxial rotors per arm (so it's possibly actually an octocopter) to provide redundancy. Though flying sounds like it would be even more of a challenge, it is actually much simpler to accomplish autonomously than driving; the surface temperature is -290 degrees Fahrenheit (-180 degrees Celsius).

Solar energy is limited on Titan due to its atmospheric haze, so Dragonfly would be powered using a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) like Curiosity and Cassini. This converts heat, from the decay of plutonium-238, into electricity. In Dragonfly's case, the MMRTG would recharge while landed, which would provide the bursts of power necessary for flight. In a single hour-long flight, Dragonfly could go further than any rovers have travelled before, flying for a few tens of kilometres, though most of its time would be spent on the ground taking data. Current plans propose making a flight once every Titan day, 16 Earth days, for up to two years, exploring areas hundreds of kilometres apart.

Dragonfly's experiments would investigate the habitability of Titan's environment, the progression of its prebiotic chemistry and evidence for hydrocarbon and water-based organisms. Not only does Titan have this Earth-like liquid cycle, but it is thought the chemical environment was similar to that of the earlier Earth. Now the Cassini mission has shown that there appears to be a global ocean of salty water under a water ice crust, along with the hydrocarbon seas on top!

"Dragonfly could go further than any rovers have travelled before, flying for a few tens of kilometres"



Hydrocarbon cycle
A mixed-hydrocarbon liquid can exist on Titan as water does on Earth – as solid (ice and snow), liquid (in rain, lakes and seas) and as a gas diffused in the atmosphere.

Rotors
Digital control and high-power electric motors have made multicopters highly controllable, yet simple, flying machines. Dragonfly will have eight rotors in four groups of two.

Instrumentation
Dragonfly's instruments will measure the composition of the surface material, the makeup of the atmosphere, listen for seismic activity and, of course, take pictures!

Battery reservoir
The RTG can't produce the bursts of high power needed for flight, so it will charge up its batteries while the probe is stationary, including overnight.

Icy crust
At Titan's low temperatures, water ice features in the landscape as a hard solid, equivalent to silicon-containing rock on Earth.

Subsurface ocean
Titan was already fascinating, but now it seems there is a global subsurface ocean, similar to Europa and Enceladus. This makes Titan a serious prospect for finding simple life beyond Earth.

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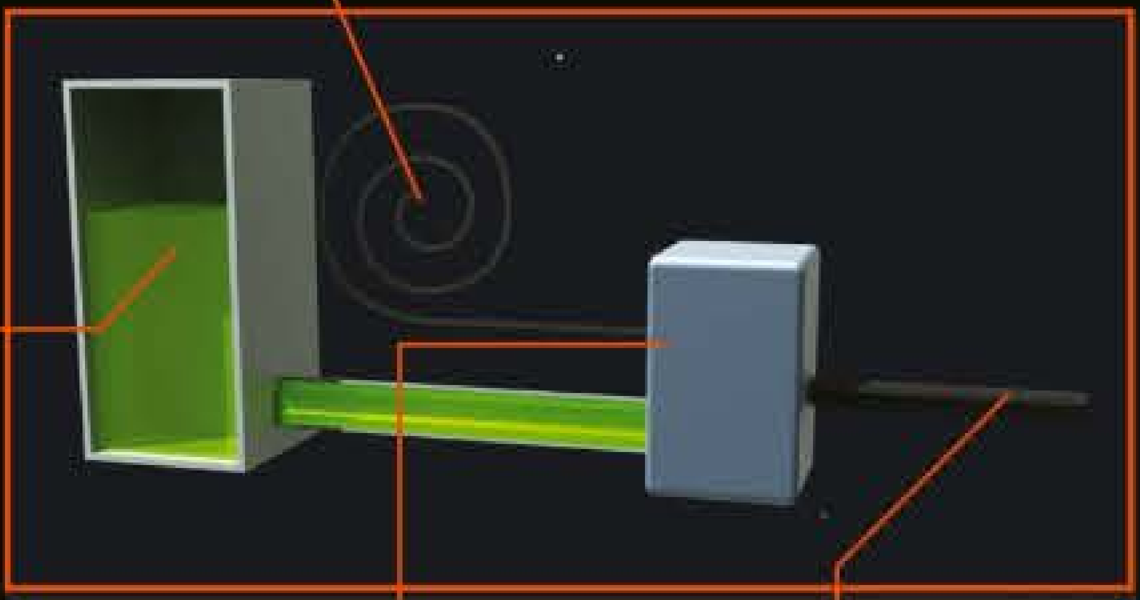
Spinning a Space Station

British company Magna Parva have a machine that could weave the space structures of your dreams

The International Space Station is the largest structure in space so far. It has been painstakingly assembled from 32 launches over 19 years, and still only supports six crew in a little-under-a-thousand cubic metres of pressurised space. It's a long way from the giant rotating space stations some expected by 2001. The problem is that the rigid aluminium modules all have to be launched individually, and assembled in space. Bigelow Aerospace will significantly improve on this with their inflatable modules that can be launched as

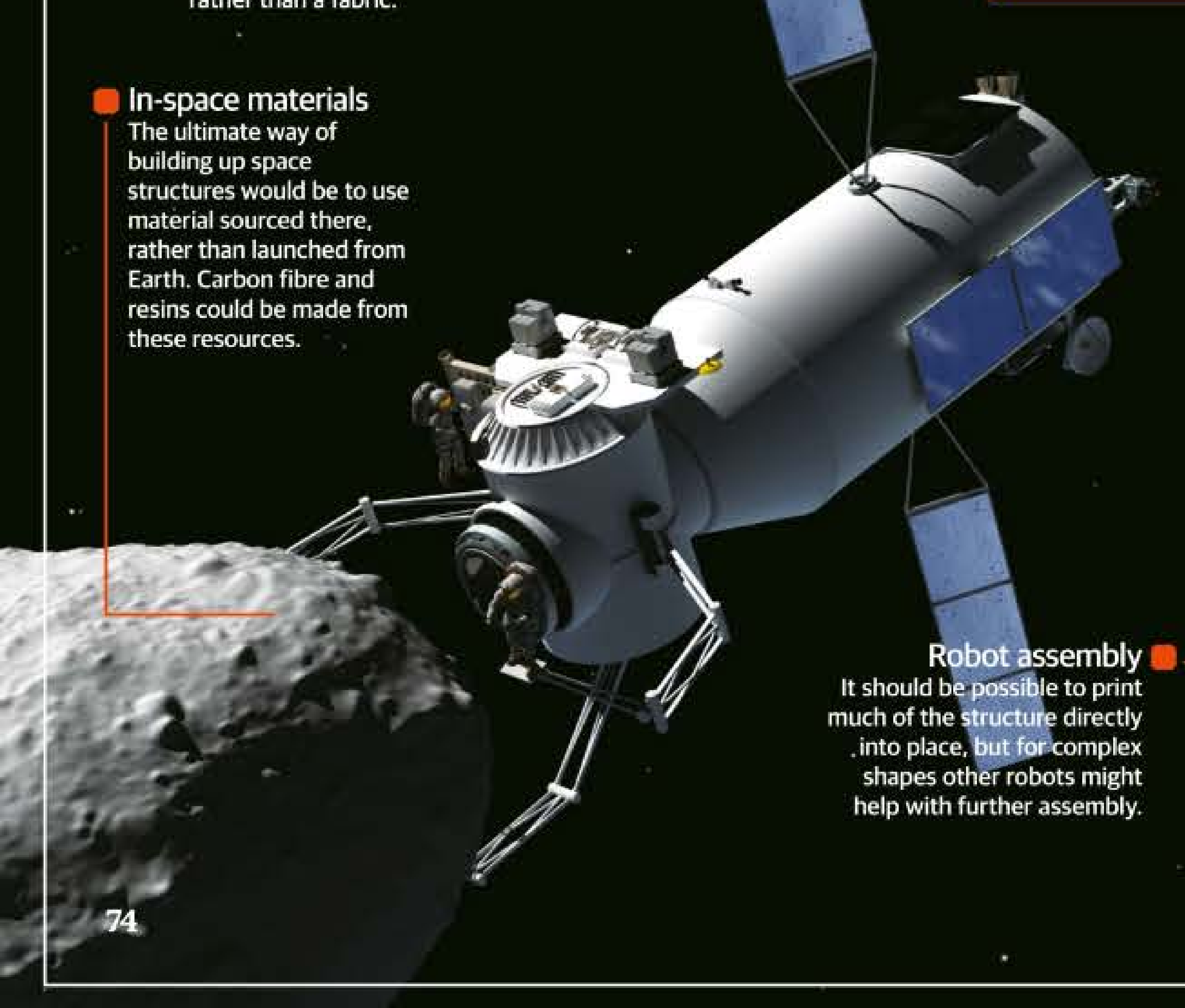


Carbon fibre
Bulk carbon fibre can be launched into space in a much smaller payload volume than sending up assembled hardware.

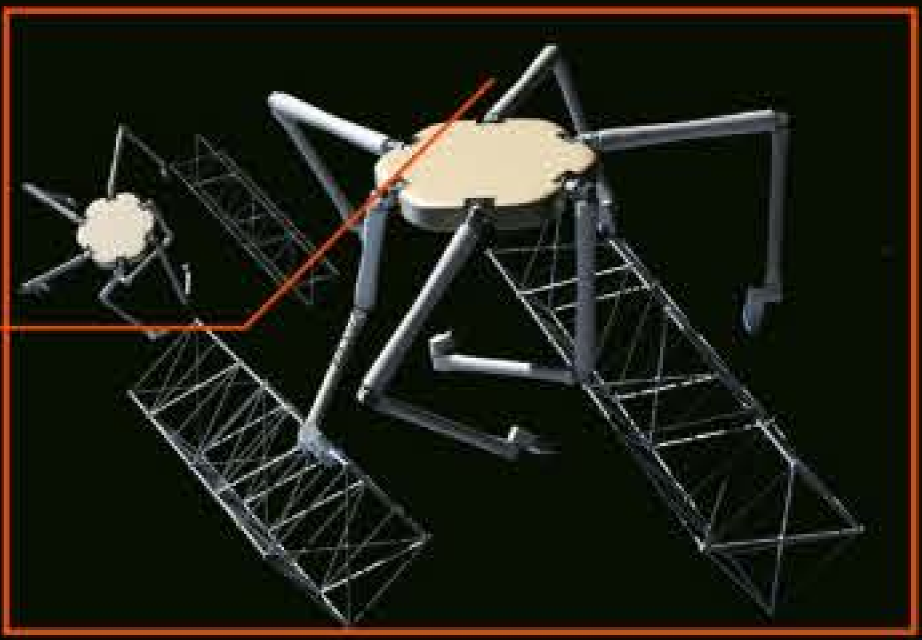
Epoxy resin
Once processed into finished composite material, the resin holds the fibres together as a solid rather than a fabric.

Composite beam
The beams can be used to construct more complex structures, antennae, or space station trusses, and could be made to any length.

Pultrusion head
The pultrusion head combines the raw materials into the finished composite beams.



In-space materials
The ultimate way of building up space structures would be to use material sourced there, rather than launched from Earth. Carbon fibre and resins could be made from these resources.



Robot assembly
It should be possible to print much of the structure directly into place, but for complex shapes other robots might help with further assembly.

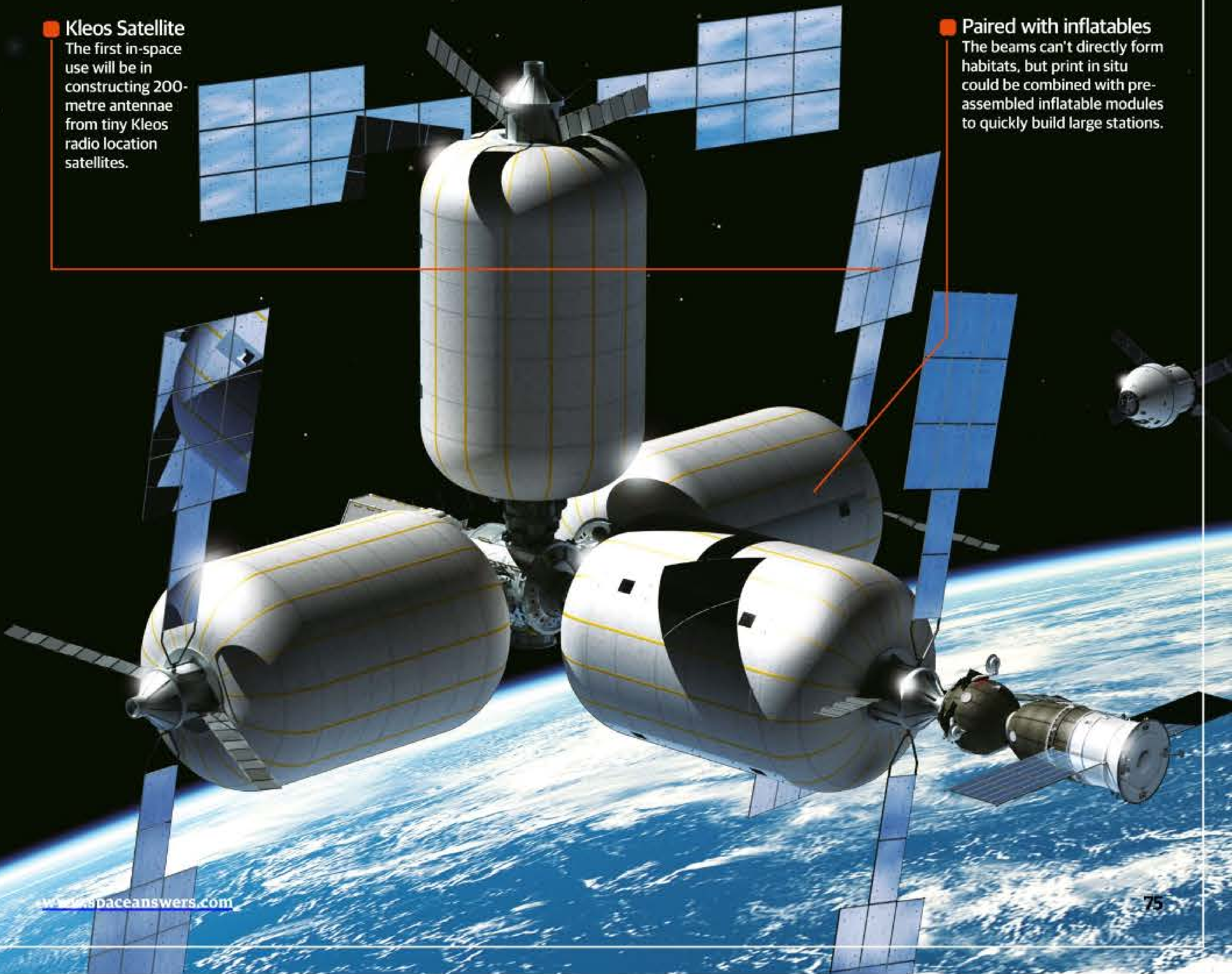
a compressed bundle; but a British company has developed a system that could transform space flight, by building structures directly in space.

Magna Parva, whose headquarters are based in Leicester, are a space engineering consultancy, founded in 2005 by Andy Bowyer and Miles Ashcroft. Their team have worked on a range of space hardware, from methods to keep Martian solar panels clear of dust, to ultrasonic propellant sensors, to spacecraft windows. But their latest project is capable of 3D printing complete structures in space, using a process called pultrusion. Raw carbon fibres and epoxy resin are combined in a robotic tool to create carbon composite beams of unlimited length – like a spider creating a web much larger than itself. Building structures in space has a range of compounding virtues, it is more compact than even inflatables, as only bulk fibre and resin need to be launched. Any assembled hardware that has to go through a rocket launch has to be made much stronger than needed in space to survive the launch, printed structures can be designed solely for their in space application, using less material still. So you can launch much more 'hardware' for a given size of rocket, and the raw material is used much more efficiently too. In addition, hydrocarbons, from which more fibres and resins could be made, are widespread in space, offering the prospect of being able to construct objects in space, from in-space resources much sooner than we might expect. Either way the system could dramatically reduce the cost, risk and time (the prototype extrudes material at 1 millimetre per second, or a mile every 18 days!) of building large structures in space.

> "Robots might be able to build us the space stations of our dreams, spun from fibres made from asteroidal material"

Incredibly, Magna Parva's prototype has already been successfully tested in vacuum conditions, and will hopefully see its first proper in-space application for the Kleos constellation. This will be a network of 20 small satellites that will be used for commercial location services by triangulating radio signals. Magna Parva's technique will be used to create 200-metre-wide antennae from a tiny central satellite. At present, the system just creates beams, so for human spacecraft it could be brilliant working in combination with Bigelow's inflatables, forming the structures to dock and connect the pressurised modules. But it may be possible to form more complex shapes in future. Magna Parva robots might be able to build us the space stations and spaceships of our dreams, spun from fibres made from asteroidal material. It would make the concept of space-based solar power (where huge panels make electricity in space and beam it to Earth) more feasible; and perhaps a similar approach could 'grow' a space elevator down from orbit.

If Magna Parva's system works as hoped, they could have a very big impact on our future in space!



Kleos Satellite
The first in-space use will be in constructing 200-metre antennae from tiny Kleos radio location satellites.

Paired with inflatables
The beams can't directly form habitats, but print in situ could be combined with pre-assembled inflatable modules to quickly build large stations.

Powerful second stage
The second stage is not currently reused, but has already demonstrated its beyond-Earth orbit capabilities by boosting Elon Musk's Tesla Roadster (used as a dummy payload for the test flight) out past Mars.

Reusable stages
Falcon Heavy can offer the lowest cost/weight launched ever achieved, in part by being able to reuse its two side cores (boosters) and central core.

Falcon Heavy
First launched in February, Falcon Heavy is the world's most powerful operational rocket, able to send up to 63.8 tonnes into orbit.

Moon mission to go!

The proliferation of new launch vehicles, habitats and landers under development means it'll soon be possible to build your own lunar spacecraft to order

When President Kennedy declared in 1961 that the US would reach the Moon before the end of the decade, it thrust NASA into uncharted territory. Only two humans had travelled into space, flying on adapted missiles, for some 108 and 15.5 minutes. No spacecraft had ever docked in space, no human had left Earth orbit and nothing at all had made a soft landing on another celestial body. Every part of the mission had to be designed, developed and, in many cases, invented from scratch. It's difficult to appreciate now how bold the plan really was.

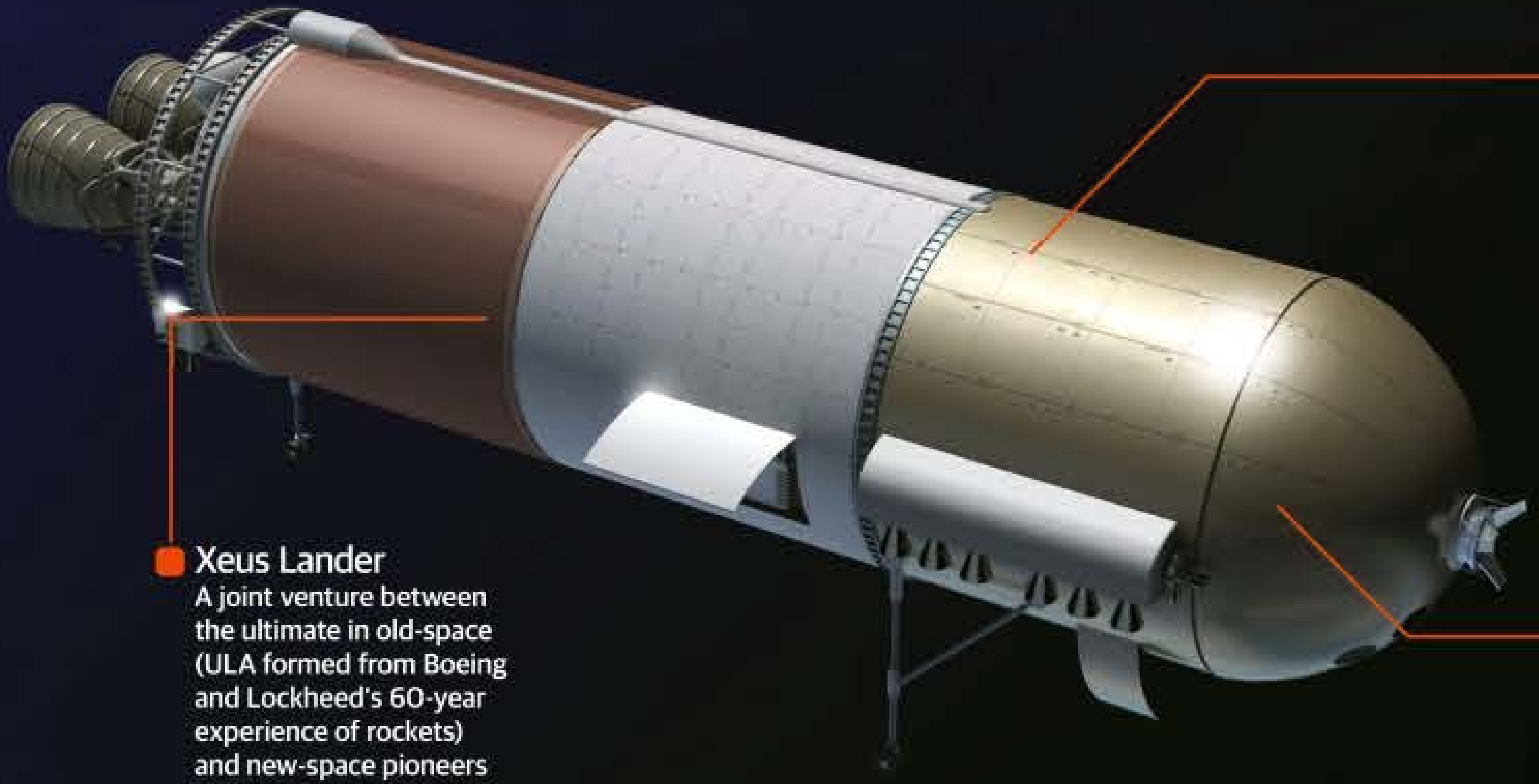
With the end of the Apollo program, the Space Shuttle was supposed to make launch cheap, easy, frequent and safe, but failed on all four counts. Commercial satellite launch became a successful, but very expensive business and robotic Solar System exploration has accomplished amazing results, but no humans have left Earth's orbit since Apollo 17 in 1972. However, since the turn of the century the space industry has been revolutionised: SpaceX has forced space launch to move forward by dramatically cutting launch costs, and along with Boeing they are on the verge of launching their own personnel transport pods for NASA. Boeing is also cooperating with Bigelow Aerospace who are developing huge pre-packed inflatable space stations, and recently had a module attached to the International Space Station. This explosion of projects, in particular mostly reusable heavy-lift rockets like SpaceX's Falcon Heavy and Blue Origin's New Glenn, moves us into fascinating territory; it is becoming possible for a country, a company or even just a rich individual to build a Moon mission out of the existing products of a number of companies.

Dr Doug Plata, a physician and space advocate, has established the Space Development Network to promote a sustainable lunar transportation project based upon this new surge in technology. He has proposed a near-term mission based on the Falcon Heavy and the United Launch Alliance's (ULA) Xeus lander, though other rockets could be used as they become available.

In Plata's proposal a robotic propellant production plant would manufacture oxygen and hydrogen supplies from lunar ice reserves. Once this fuel depot is established Falcon Heavys could pitch 20 tonnes directly towards the Moon, which would be exchanged with a Moon-refuelled lunar lander halfway there, and there is an innovative lander almost, comparatively, ready to go.

The Xeus lander is a concept created by ULA in cooperation with new-space company Masten Space Systems. It proposes to use ULA's Centaur,

> "It is becoming possible for a country, a company or even just a rich individual to build a Moon mission"



Horizontal landing
Rather than land vertically on the Moon, the existing Centaur main engines would only be used for in-space propulsion, and Masten would provide four small engines to land the stage sideways.

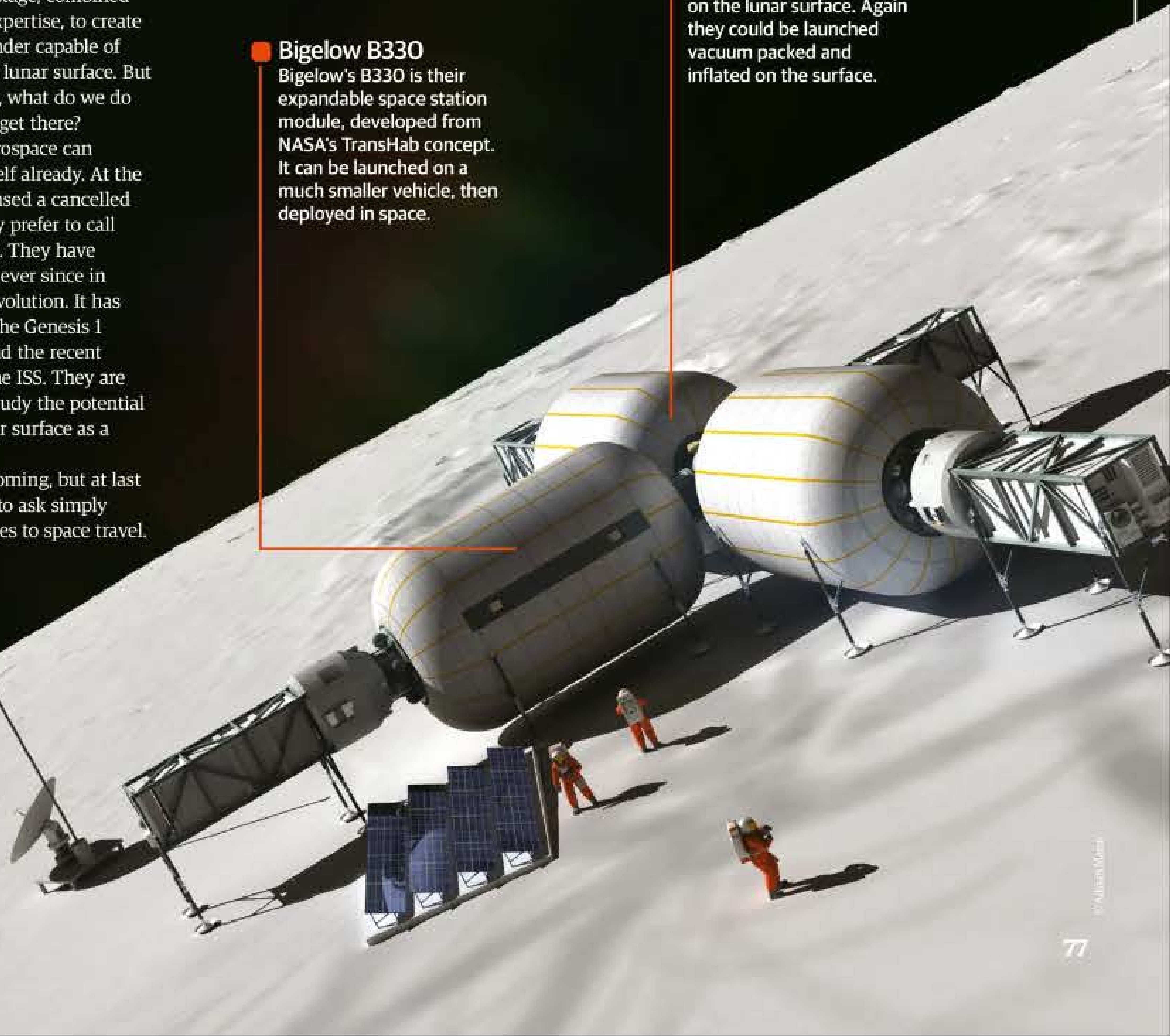
Xeus Lander
A joint venture between the ultimate in old-space (ULA formed from Boeing and Lockheed's 60-year experience of rockets) and new-space pioneers Masten Space Systems.

Centaur upper stage
First flown in the early 1960s, the Centaur was created as a high energy second stage by Convair for the Atlas rocket; it has since been used for many important exploration launches.

a high-energy, upper rocket stage powered by liquid oxygen and liquid hydrogen, and its earliest version was first launched in 1962. Over its 56-year career it has propelled the Viking Martian orbiters and landers, both Voyagers and Cassini on interplanetary missions. ULA hope to be able to build upon the reliability of the stage, combined with Masten's vertical landing expertise, to create a relatively inexpensive lunar lander capable of delivering up to 10 tonnes to the lunar surface. But getting to the Moon is one thing, what do we do about accommodation when we get there?

Well this is where Bigelow Aerospace can nearly pull something off the shelf already. At the turn of the century Bigelow licensed a cancelled NASA concept for inflatable (they prefer to call them expandable) space stations. They have been developing the technology ever since in anticipation of a space launch revolution. It has been demonstrated in space by the Genesis 1 and 2 unoccupied prototypes, and the recent addition of their BEAM pod to the ISS. They are already working with NASA to study the potential use of their modules on the lunar surface as a prefabricated habitat.

It has been a very long time coming, but at last we're on the verge of being able to ask simply "Where", not "How" when it comes to space travel.



Surface habitats
NASA and Bigelow have been studying the potential use of the B330 on the lunar surface. Again they could be launched vacuum packed and inflated on the surface.

Bigelow B330
Bigelow's B330 is their expandable space station module, developed from NASA's TransHab concept. It can be launched on a much smaller vehicle, then deployed in space.

Collapsible systems
As well as OSS, Magna Parva are looking to print carbon fibre booms in space and Bigelow Aerospace are working on inflatable habitats.

Panel ridge origami
While traditional origami works by creasing material, OSS do not want creases in the antenna surfaces. The membrane is thickened along the fold lines, so it bends but doesn't crease.

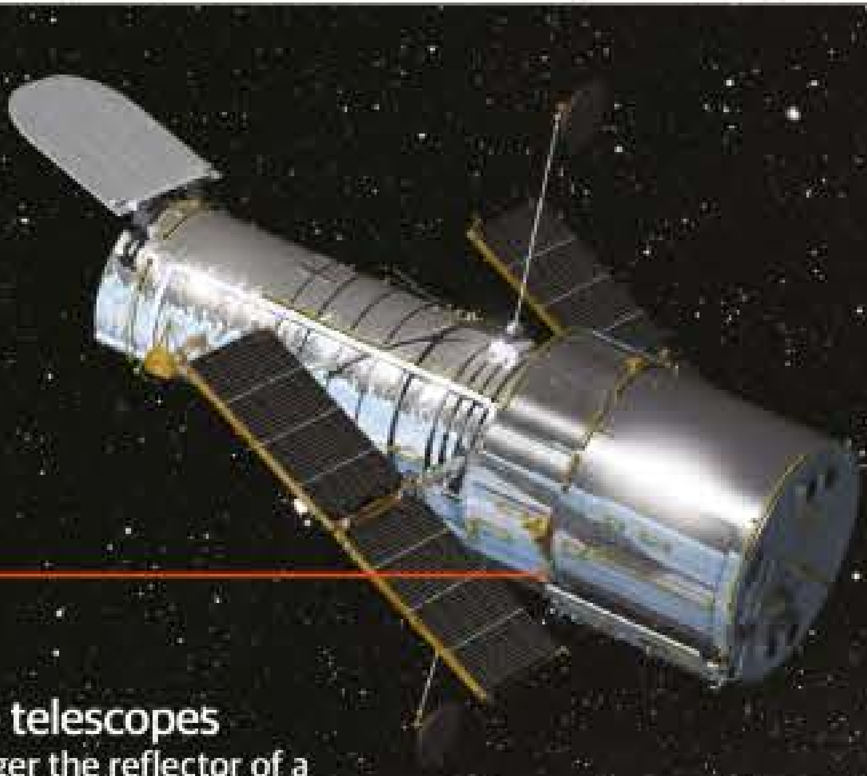
Origami spacecraft

A British space technology company is using ancient Japanese paper folding to pack up missions

NASA's next great observatory, the James Webb Space Telescope, will be 12 years late with a cost of $8.8 billion. One of the contributing factors has been the need to pack a huge 6.5-metre 18-piece telescope mirror (Hubble's is a single piece with a 2.4-metre diameter) away in a 5.4-metre diameter rocket (Ariane 5). In the near future, British start-up, Oxford Space Systems hopes to enable much larger structures to be more conveniently (and cost effectively) launched into space, and they are studying origami, the ancient Japanese art of paper folding, to help them.

Oxford Space Systems (OSS) was founded in 2013 by engineer Mike Lawton, after he spent some 16 years working in the British space industry. OSS specialise in deployable space structures – the booms and panels that make up satellites and space stations and foldable antennae for communications. With launch costs ranging from around $50 to $500 million, it is very important to minimise the total mass you need to launch, to reduce these costs. This is what led OSS to look at origami. "To work out the best way to fold these space systems to fit inside a launch rocket, we had to ask ourselves: has anyone figured out a really smart way to fold things? The answer was yes – origami experts – and it turns out they've been doing it for a really long time," says Lawton.

While researching the field, Lawton came across Professor Zhong You of Oxford University; You was fascinated by OSS's challenges and immediately invited Lawton to his laboratory. "We didn't leave his office for four hours that day, spending most of the morning looking around his laboratory. It was like a toy shop, and was full of exciting prototypes and fantastic concepts!" As it happens, the art of origami is actually very amenable to mathematical modelling, providing a useful design tool for spacecraft development; though Professor You starts by building physical experimental structures before working backwards in order to define what their mathematical characteristics are.



Space telescopes
The larger the reflector of a telescope, the better its light gathering capability. Hubble's 2.4-metre mirror meant it was able to fit in the Space Shuttle, with folded solar panels.

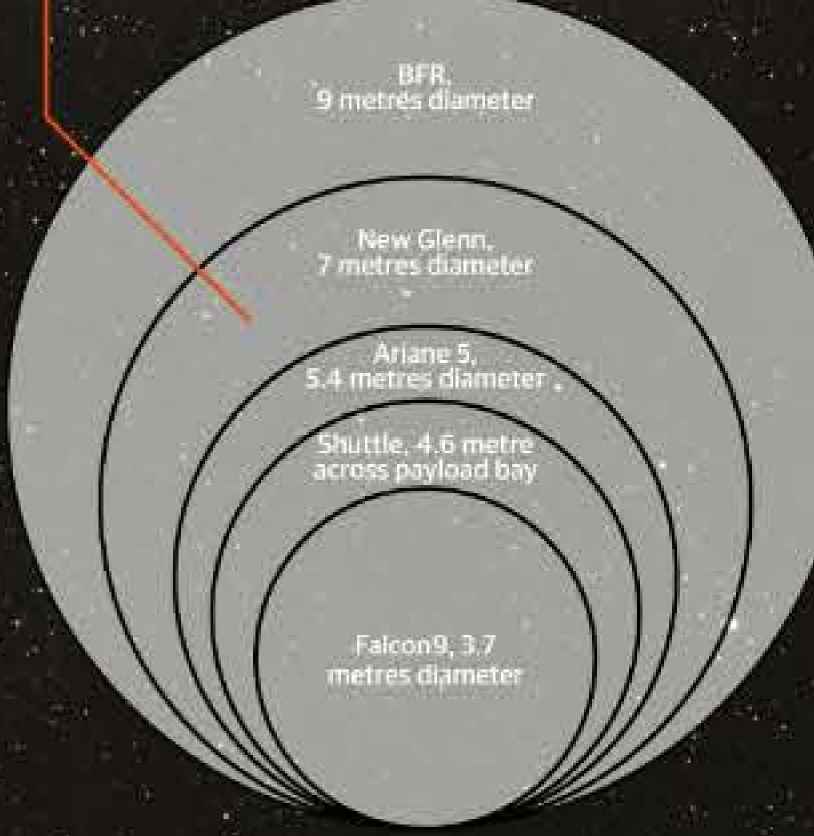
Antennae
The bigger the antenna, the better it works, as it can focus signals from a larger collection area. OSS's collapsible antennae would speed up space-based communications.

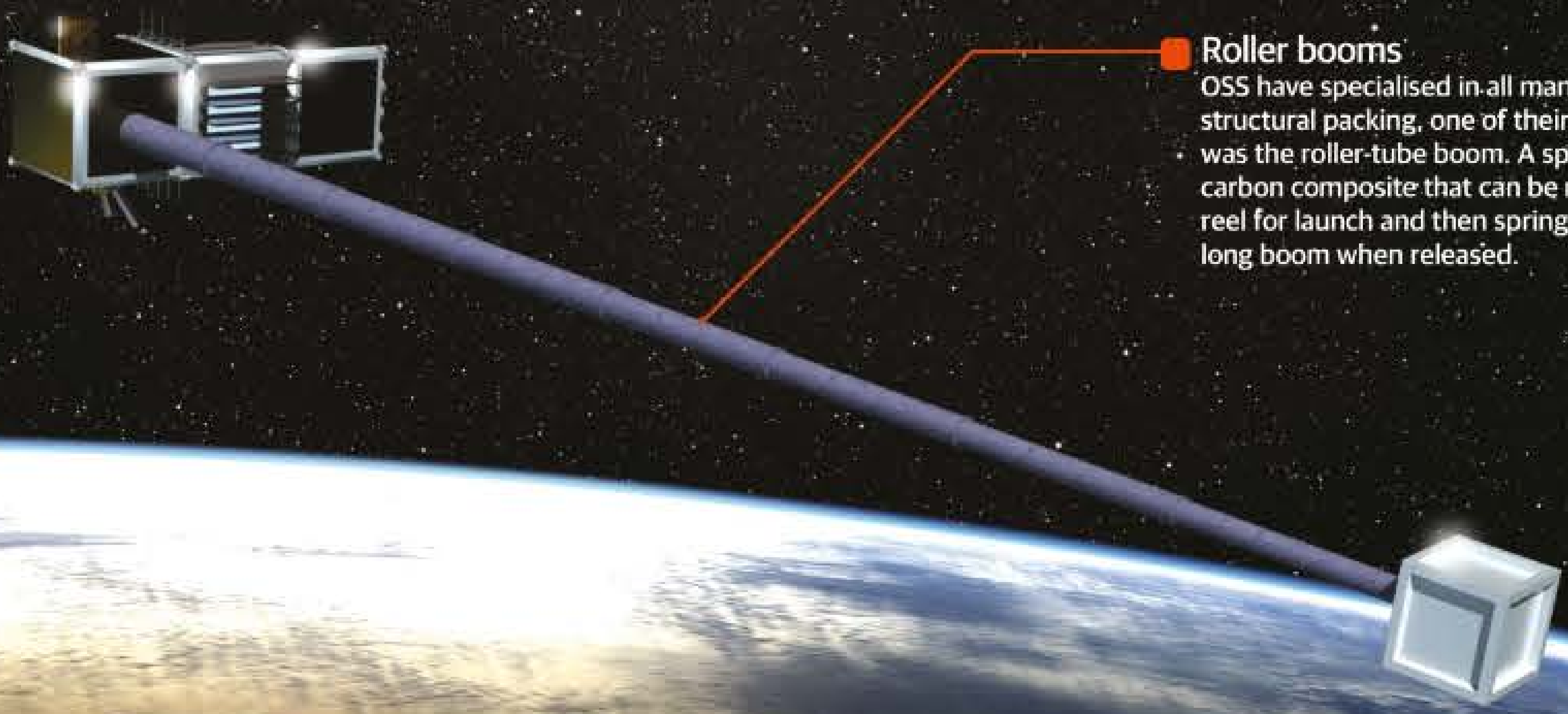
OSS' current focus is on creating foldable antennae, which will be up to 12 metres in diameter once deployed. However, unlike traditional origami they are specifically trying to fold the material without creasing it. Lawton explains: "We're adding thickness to the folds. We're working with an advanced type of origami because it involves much more complex mathematics - panel-ridge origami." Ultimately though, OSS want to move beyond one-off prototypes and onto the mass production of standardised collapsible components. "We're developing tech that targets constellations - thousands of satellites in space for internet and other services - and I want to make sure that it's our tech developed in the UK that's the most contracted presence in these constellations," Lawton says.

Oxford Space Systems' designs complement other expandable technology, like Magna Parva's printed-in-space carbon fibre beams. Together they could fit extraordinary spacecraft into existing launch vehicle payload fairings, but the most intriguing possibility is what they could do with SpaceX's Big Falcon Rocket. Predicted to replace SpaceX's existing Falcon 9 rocket and Dragon capsule, the reusable BFR will be 9 metres in diameter and could launch the James Webb mirror in one piece. Imagine what we could do if we combined these new technologies to fit huge structures into large rockets, with a huge rocket!

> "Origami is very amenable to mathematical modelling, providing a useful design tool for spacecraft development"

Cargo cross sections
Space-race era spacecraft tended to be dedicated designs, but now most payloads are launched in standardised payload fairings or cargo bays.


BFR, 9 metres diameter
New Glenn, 7 metres diameter
Ariane 5, 5.4 metres diameter
Shuttle, 4.6 metre across payload bay
Falcon9, 3.7 metres diameter



Roller booms
OSS have specialised in all manners of structural packing, one of their first products was the roller-tube boom. A split cylinder of carbon composite that can be rolled up in a reel for launch and then springs out into a long boom when released.

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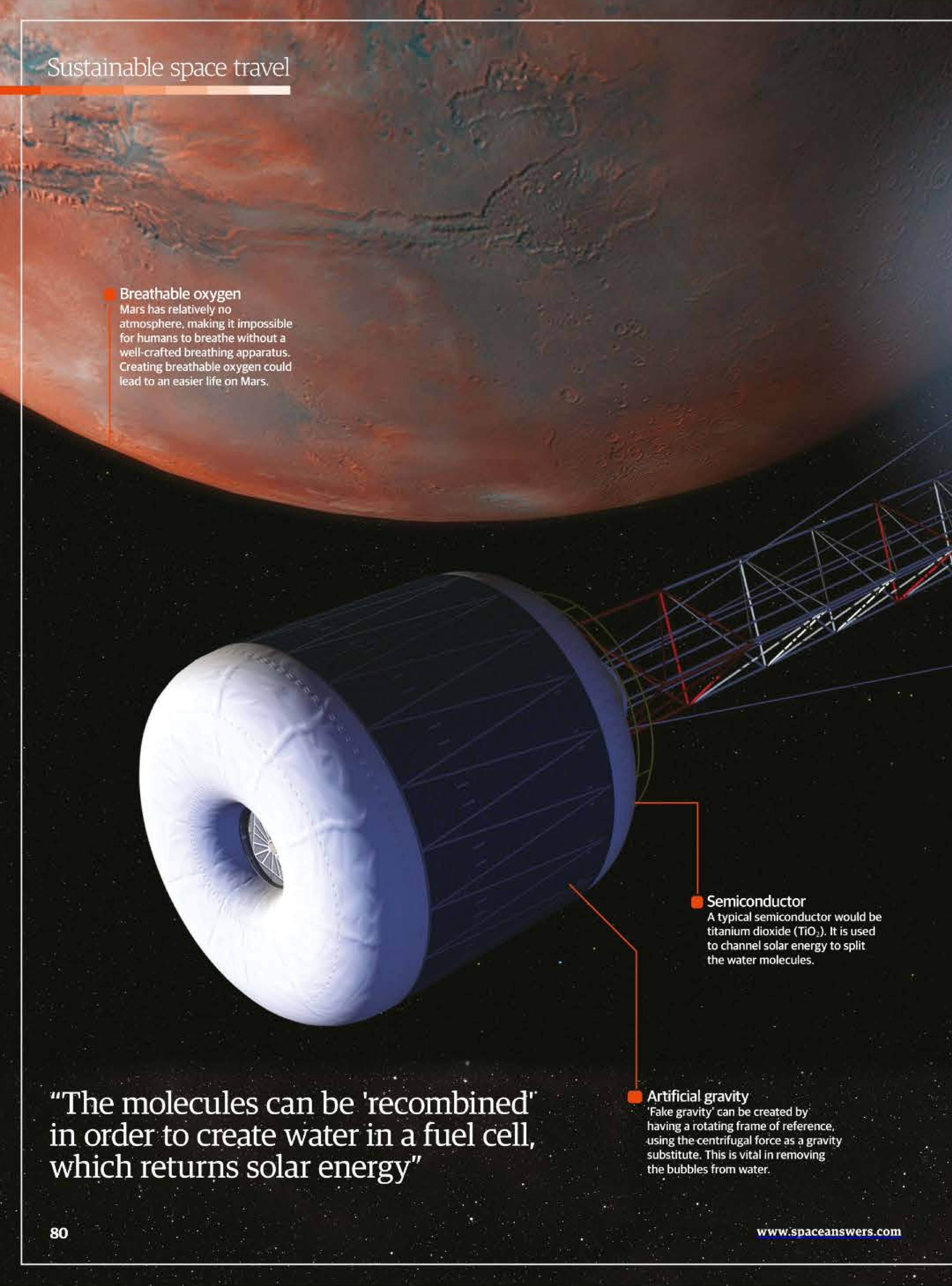
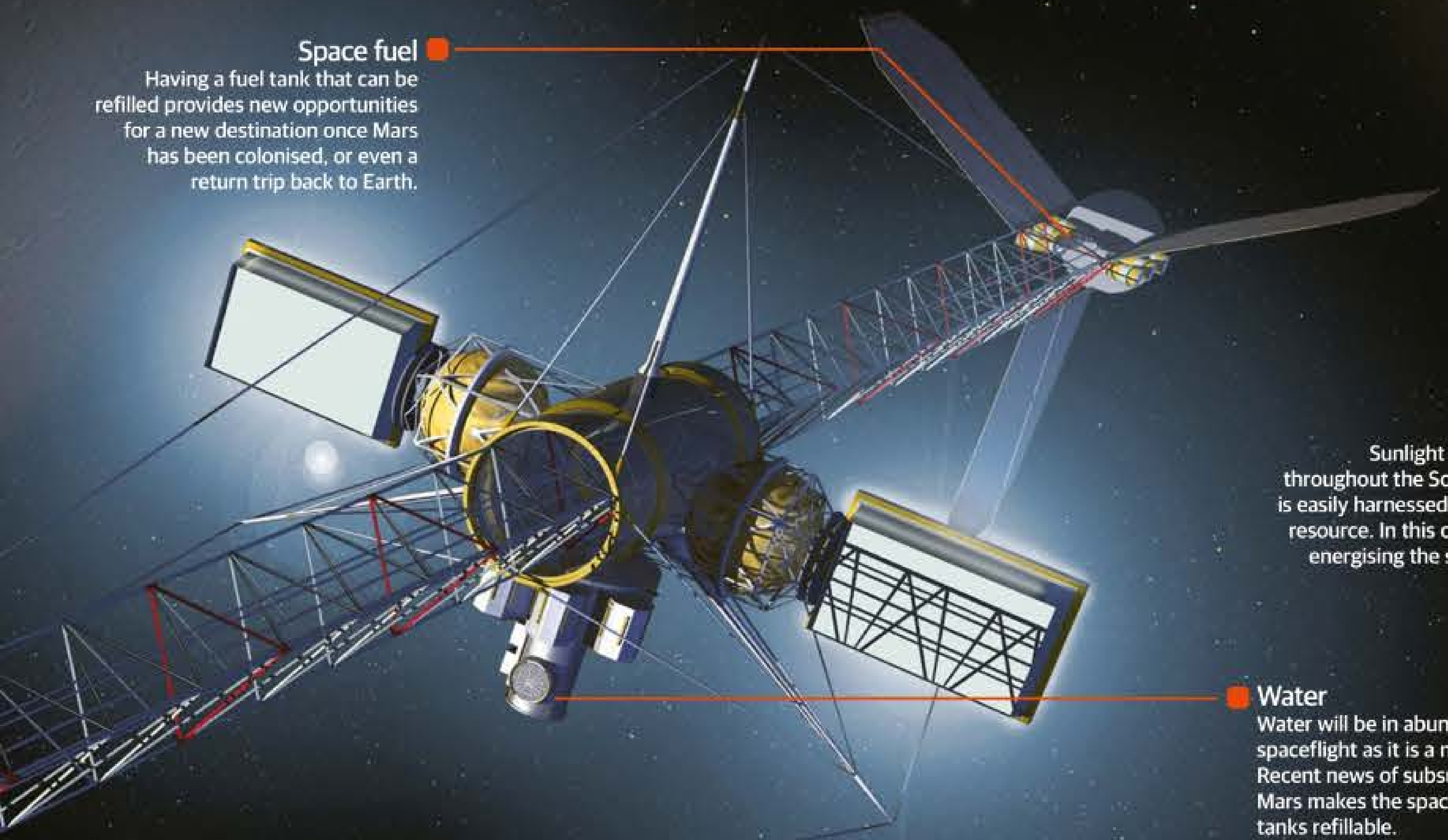


Breathable oxygen
Mars has relatively no atmosphere, making it impossible for humans to breathe without a well-crafted breathing apparatus. Creating breathable oxygen could lead to an easier life on Mars.

Semiconductor
A typical semiconductor would be titanium dioxide (TiO_2). It is used to channel solar energy to split the water molecules.

Artificial gravity
'Fake gravity' can be created by having a rotating frame of reference, using the centrifugal force as a gravity substitute. This is vital in removing the bubbles from water.

> "The molecules can be 'recombined' in order to create water in a fuel cell, which returns solar energy"



Space fuel
Having a fuel tank that can be refilled provides new opportunities for a new destination once Mars has been colonised, or even a return trip back to Earth.

Sunlight
Sunlight is ever-present throughout the Solar System and is easily harnessed into a valuable resource. In this case it is vital to energising the semiconductor.

Water
Water will be in abundance in any spaceflight as it is a necessity for life. Recent news of subsurface water at Mars makes the spacecraft's water tanks refillable.

Sustainable space travel

Creating fuel and breathable oxygen during humanity's voyage through the Solar System and beyond is essential

A new study, recently published in *Nature Communications*, has proposed a new way to manufacture oxygen (to breathe) and hydrogen (for spacecraft fuel) while in space. The idea involves transporting large amounts of water (H_2O) on board the spacecraft, a semiconductor material and the ever-present resource that is sunlight. The idea behind the process is to split molecules of water into their constituent atoms using an electric current.

There are two ways of separating water molecules. One way is through a process known as electrolysis, which involves passing an electric current through a water sample containing some soluble electrolyte. This will break down water into hydrogen and oxygen and they are collected at different electrodes. Although this is theoretically possible, the equipment is not readily available and appropriate for spaceflight as of yet.

The method proven more appropriate for spaceflight is a process called 'photocatalytic water splitting'. In this scenario, a semiconductor is inserted into the water and absorbs photons, which gives enough energy to an electron on the semiconductor to jump and leave a hole. This free electron can then interact with protons to form hydrogen, whereas the hole absorbs electrons from the water to form protons and oxygen.

This process can also be reversed, and the molecules can be 'recombined' in order to create water in a fuel cell, which returns solar energy. The idea that three vital elements for long-term space travel - water, hydrogen and oxygen - can be used and created in a sustainable way is tantalising. The only issue with this is what to do with the bubbles.

The researchers wanted to test the viability of the photocatalysis in space by setting up an experiment down a 120-metre (394-foot) drop tower. With an object in freefall, gravity is essentially nonexistent, creating the perfect environment to test experiments without actually going to space. During the drop the researchers showed it is possible to split the water, but there is a problem with the bubbles that are created.

When bubbles are created on Earth, gravity automatically makes sure the bubbles rise to the top and dissipate. In space the bubbles do not know where to go and permeate the water. If the bubbles were to stick on the catalyst, there would be no free room for the next bubble to form. The researchers combated this problem by creating pyramid-shaped zones where the bubbles could easily be released from the catalyst. However, there was still a problem with the evacuation of bubbles from the liquid. To prove viable there needs to be artificial gravity, as it will provide the force needed to evacuate the bubbles from the water.

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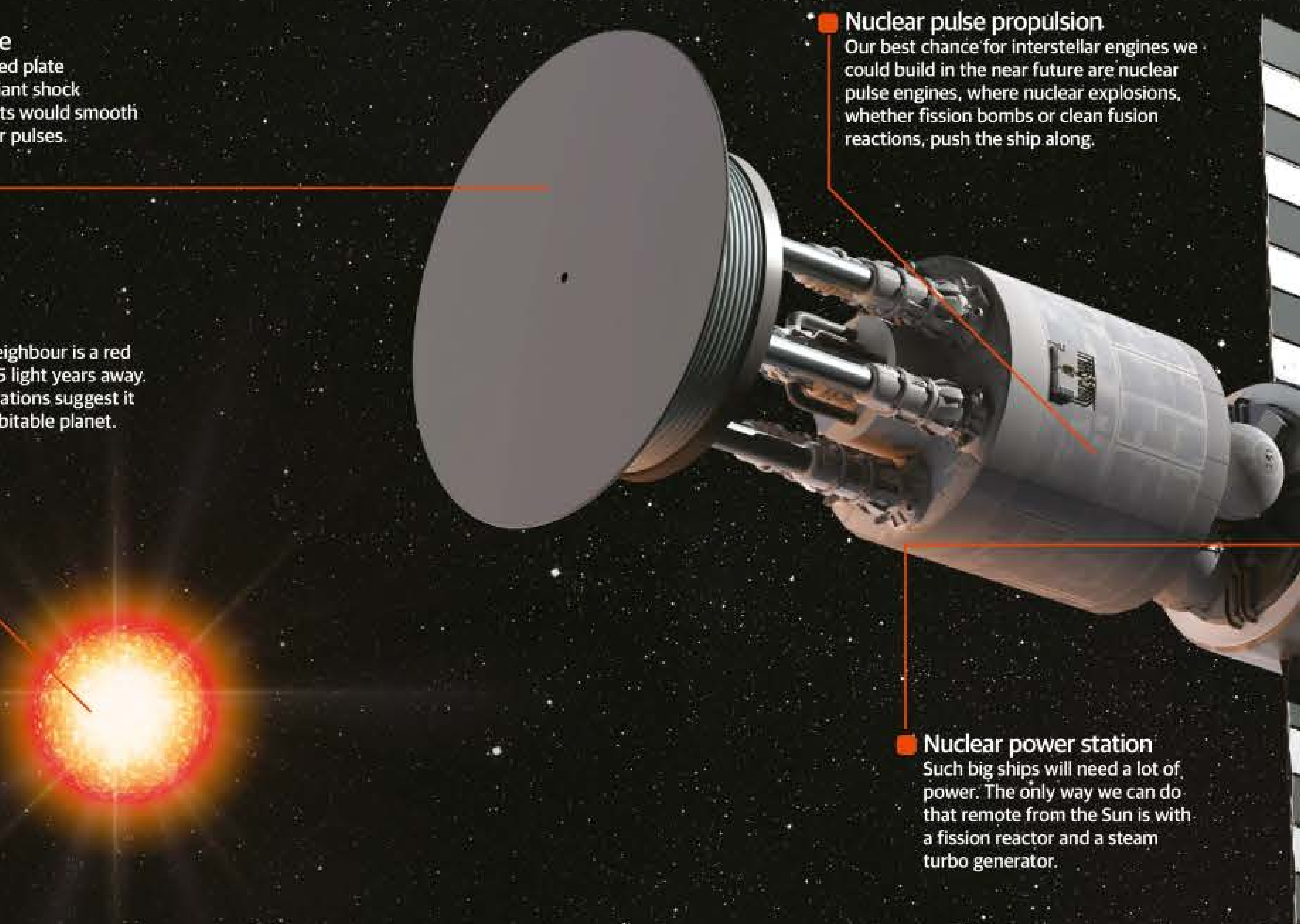


Pusher plate
A huge insulated plate mounted on giant shock absorbing struts would smooth out the nuclear pulses.

Proxima b
Our nearest neighbour is a red dwarf star 4.25 light years away. Recent observations suggest it may have a habitable planet.

Nuclear pulse propulsion
Our best chance for interstellar engines we could build in the near future are nuclear pulse engines, where nuclear explosions, whether fission bombs or clean fusion reactions, push the ship along.

Nuclear power station
Such big ships will need a lot of power. The only way we can do that remote from the Sun is with a fission reactor and a steam turbo generator.

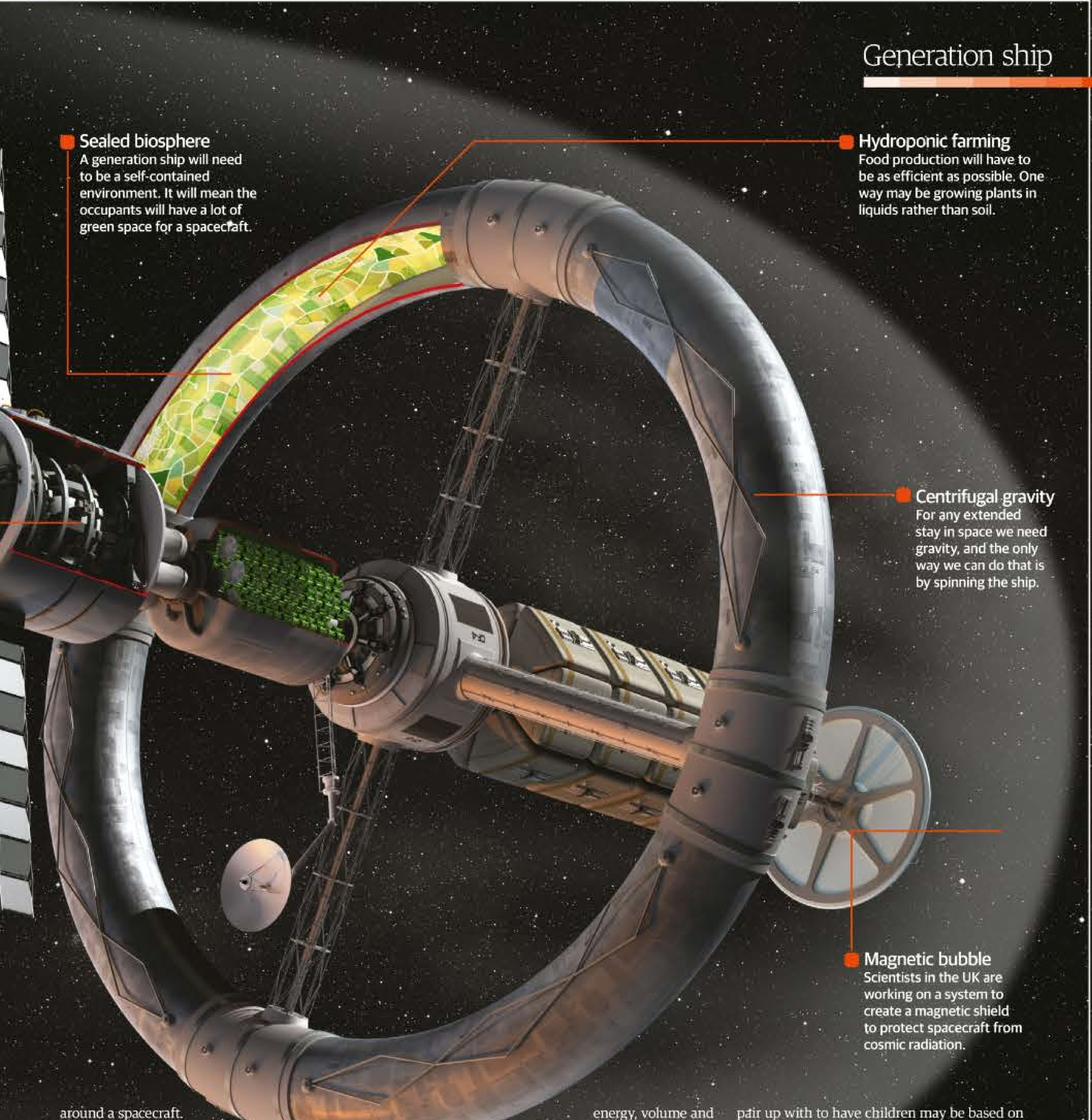
Generation ship

Barring a propulsion breakthrough, humanity's best chance of reaching other star systems could be generation ships: flying colonies that would spend centuries in transit

While we still struggle to scale interplanetary distances, various research groups have carried out serious study into interstellar travel. These distances are inconceivably vast - our nearest stellar neighbour, a red dwarf called Proxima Centauri, is about 4.25 light years or over 40 trillion kilometres (25 trillion miles) away. Though we are accustomed to the idea of skipping between star systems through fiction, barring a breakthrough propulsion discovery the best propulsion systems we can foresee would still take us a century to reach Proxima Centauri. This has led some writers and researchers to propose generation ships. A generation ship is the concept of a large, self-sustaining space colony where several generations of space travellers would live over the century, or even centuries, it would take to reach another star system. But such a ship proposes myriad questions, both technical and ethical.

To be able to make a journey a ship needs an engine, and remarkably we already have an interstellar-capable propulsion system within reach, though with one big drawback. Project Orion was a large scale, serious project studied by the US between 1958 and 1963 to propel a spaceship by detonating atomic bombs behind it. Rather than destroy the ship, bombs of just the right size would push a prospective ship along by impinging on a suspended pusher plate - like a giant atomic pogo stick! It was determined that this approach would actually be very efficient, and because the energy packets are so large the engine needs a large ship to go with it. Baseline studies proposed a 40-metre (131-foot) diameter dome weighing 4,000 tons that would be able to go from Earth's surface, to Jovian orbit and back again in a single stage. In the end it was determined that one flight to Mars would statistically kill 100 people globally by the nuclear pollution that would be sucked back to Earth by our magnetic field. But if fired up at a safe distance in a solar orbit an Orion could ultimately achieve 10 per cent the speed of light; it is an interstellar engine we already know how to build.

Another issue we need to tackle just to live in free-floating space colonies for any time, travelling or not, is radiation protection. High-energy cosmic rays and particles of all types surge around space, and without a planetary atmosphere or magnetic field humans are vulnerable to long-term damage from them. To this end researchers at Rutherford Appleton Laboratory in the UK are working on a way to generate an artificial magnetic bubble



Sealed biosphere
A generation ship will need to be a self-contained environment. It will mean the occupants will have a lot of green space for a spacecraft.

Hydroponic farming
Food production will have to be as efficient as possible. One way may be growing plants in liquids rather than soil.

Centrifugal gravity
For any extended stay in space we need gravity, and the only way we can do that is by spinning the ship.

Magnetic bubble
Scientists in the UK are working on a system to create a magnetic shield to protect spacecraft from cosmic radiation.

around a spacecraft. This would redirect cosmic radiation around the ship protecting the crew, just like *Star Trek*. Initial testing is looking promising, but it will need a lot of electricity, so the ship will need its own nuclear power station on board to run everything. And there's going to be a lot to power; one study suggested the ship would need to set off with more than 160 people on board to ensure genetic diversity over the flight time. That's a big ship and a lot of people needing air and water constantly cleaned and recycled, not to mention food production. Food would have to be made as efficiently as possible using the least energy, volume and water. Plants could be grown hydroponically in liquid rather than soil, algae and mushrooms could be cultured in vats for protein, and fish could probably be effectively farmed. On top of all of that the whole structure will have to spin to provide gravity.

Perhaps larger than the technical challenges are the ethical ones; travellers setting off on a generation ship are compelling their initial descendants to spend their whole lives in a small, closed community and environment on the basis later descendants might get to settle on a new planet. To ensure a healthy community who you pair up with to have children may be based on your genetic files rather than your interests. Automation should enable reasonable free time, but to keep a closed environment running for centuries will mean career choices will be limited to what needs doing. There would also be no escape if the community turned totalitarian, or if illness struck. What about the mental well-being of the crew if 100 years into the flight a warpship turns up to collect them having been invented in the meantime?

Generation ships are probably possible within the next 100 years, but are probably only ethical if Earth is otherwise lost… Probably best if we wait on the warpdrive.

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Solar System

Finding out about our planetary neighbours

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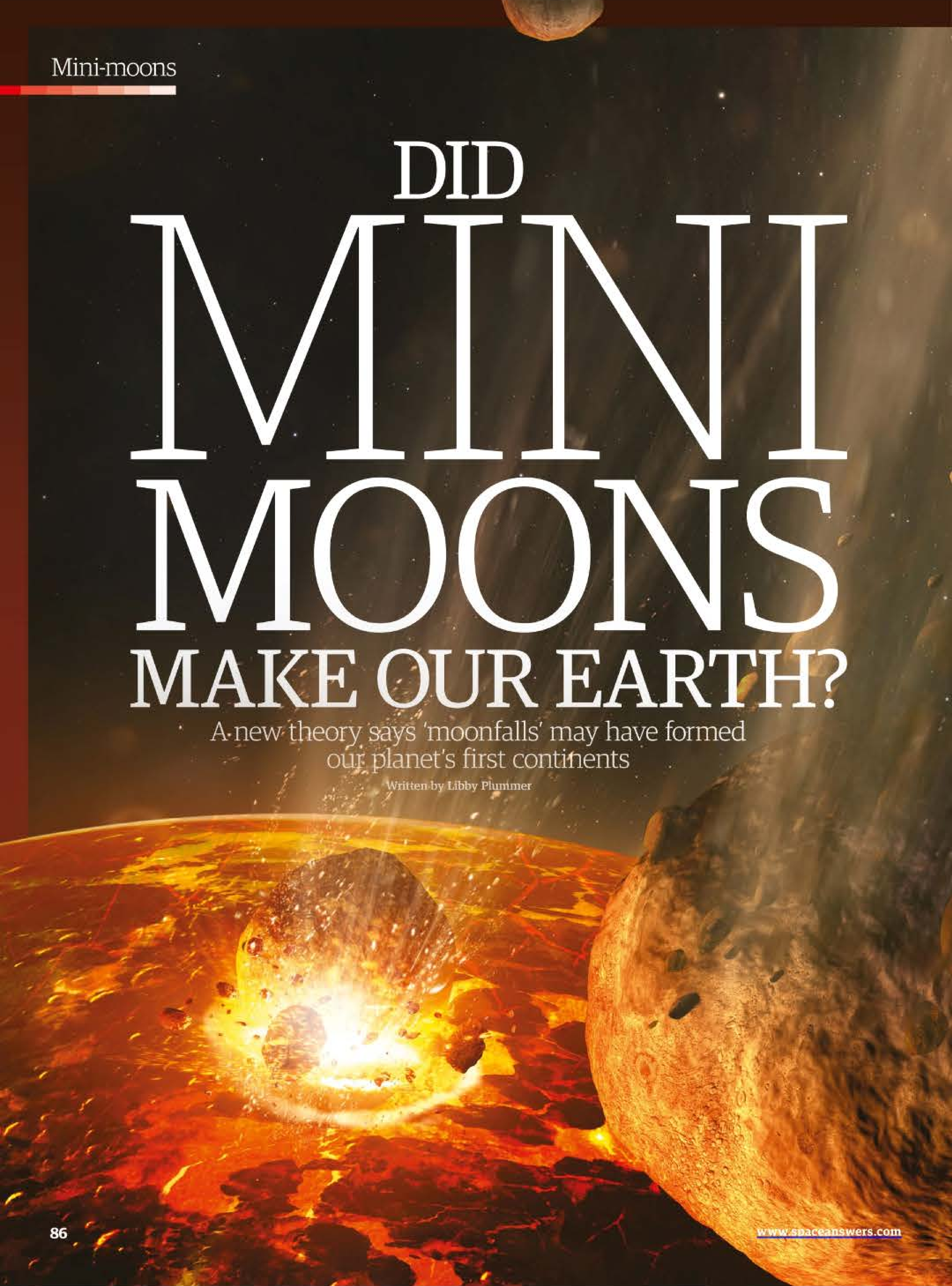
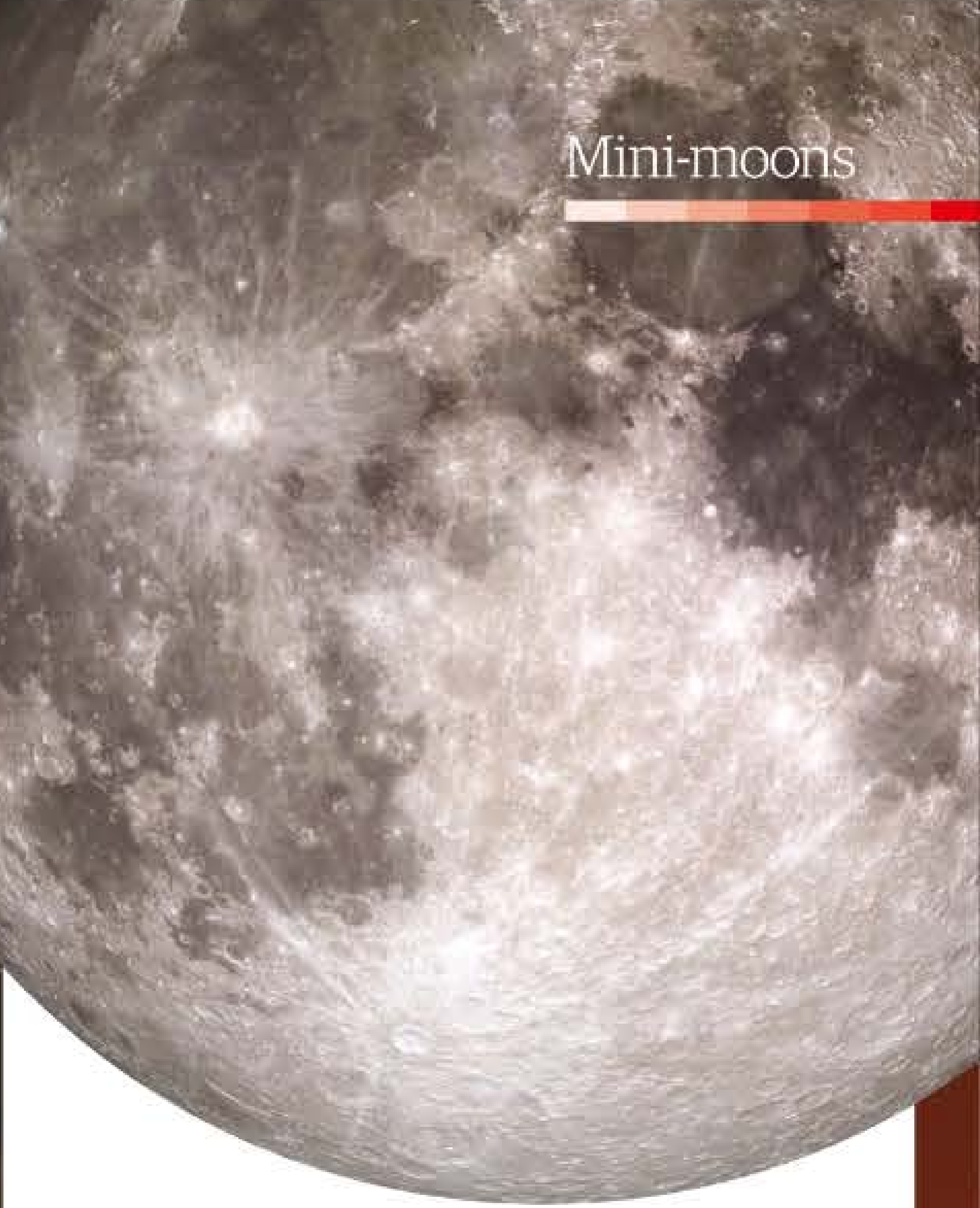


DID MINI MOONS MAKE OUR EARTH?

A new theory says 'moonfalls' may have formed our planet's first continents

Written by Libby Plummer



Mini-moons may have battered Earth with debris in its formative years, shaping the young planet and maybe even building the first continent. That's the theory put forward by a new study which turns the 'giant-impact hypothesis' on its head.

In the well-established giant-impact theory, a Mars-sized rocky object called Theia smashed into what would become Earth around 100 million years after the Solar System was formed. The giant collision spewed debris up into space forming a disc of debris, some of which gradually came together to form our Moon.

This idea was initially put forward in 2012, and then four years later, researchers at the University of California, Los Angeles (UCLA) published new evidence to cement the theory. While it was previously thought that the collision, which took place around 4.5 billion years ago, was a powerful, angled side-swipe by the giant rock Theia, the new evidence confirmed it was likely to have been a violent, head-on smash. The team came to this conclusion after analysing seven rocks brought back to Earth by the Apollo 12, 15 and 17 lunar missions, along with six volcanic rocks from the Earth's mantle. A shared chemical signature in the oxygen atoms both in the Moon rocks and the Earth rocks made it likely that a head-on collision had occurred, the researchers concluded.

"Theia was thoroughly mixed into both the Earth and the Moon, and evenly dispersed between them," said Edward Young, UCLA professor and lead author of the study, speaking at the time of its publication. "This explains why we don't see a different signature of Theia in the Moon versus the Earth." The study explains that the alternative, a glancing side blow from Theia, would have meant that the vast majority of the Moon would have been formed from Theia, and that the Earth and Moon would have different chemical 'fingerprints'.

© NASA; Tobias Roetsch

However, a series of recent studies argue that the Moon wasn't formed by a single collision alone, but rather a series of impacts. The latest research, which at the time of writing had been published online and has been accepted for publication in the *Monthly Notices of the Royal Astronomical Society*, suggests that multiple impacts on Earth would have blown debris back into orbit, which then came together to form our Moon, along with lots of smaller mini-moons or 'moonlets'. Complex movement between these moonlets would have slowly changed their orbits, gradually making them more elliptical. Many of them would then have crashed down on to the proto-Earth, battering the fledgling planet time after time. These 'moonfalls' would have caused a build-up of material in localised spots, leading to the formation of topographical features and potentially even the Earth's first continent. The researchers were able to demonstrate the hypothesis using a series of simulations. The study was based on smoothed-particle hydrodynamical (SPH) simulations, where a computer is used to reproduce processes such as star formation and meteor impacts.

This new theory was put forward as the researchers believe that the widely accepted idea of how the Moon was formed doesn't quite add up.

"The current [giant-impact] paradigm is intrinsically incomplete and disconnected from the wider picture of terrestrial planet formation in which the proto-Earth had experienced and grown though multiple planetary-scale impacts," co-author of the new study Hagai Perets from the Technion Israeli Institute of Technology explains to **All About Space**. "Consideration of only the last such impact in the current paradigm disregards the critical evolution taking place prior to – and possibly following – this event."

That's why the researchers investigated the new scenario in which Earth's Moon may be the result of a merger of lots of mini-moons, and where Earth's geophysical and geochemical make-up was altered by the multiple-impact evolution of the Moon.

"The current paradigm is challenged by several major difficulties, as mentioned in this and previous papers," says Perets. "Generally, the multiple-impact model we suggest naturally connects Earth's Moon formation with the global formation of the Solar System, and potentially constrains it. These issues and challenges call for a paradigm shift, and motivate the novel conceptual framework we propose. The current paper on Earth-Moon collisions is one piece in this new model, and we are working on several other implications, such as studying Moon-moon collisions."

The new theory builds on research published last year from Perets and a different inter-university team which challenges the most prevalent theory of how the Moon formed. It suggests that the Moon that we see is not Earth's first moon, but the latest in a series of rocky satellites, and that it was formed by a series of impacts rather than one big smash.

While the idea of one major collision is currently the accepted theory, the researchers behind the recent studies claim that this scenario requires very specific conditions, which are rare. They claim that the idea of a series of impacts is far more feasible.

"The multiple-impact theory is a more natural way to explain the formation of the Moon," Raluca Rufu from the Weizmann Institute of Science tells **All About Space**. "It does not require one single and specific impact, but rather incorporates all the possible impactors Earth experienced during the late accretion stage [when Earth was formed]. Each moonlet accretes from a different debris disc and eventually merges with previous existing moonlets at low velocities, where the mixing between the two components is not efficient. This can explain some of the observed lunar heterogeneities in the Moon's interior," said Rufu, lead author of the research study, published in *Nature Geoscience* last year.

The authors admit that there are limitations to the new multiple-impact hypothesis, largely that it is based on a limited dataset, making it harder to model possible collisions.

"In the current model we explore the implications of moonfalls on the Earth using simulations of the impacts themselves, making use of a hydrodynamical code," explains Perets. "We consider a grid of models for the initial properties of the impact [position of the impact, size of the impacting moon, rotation of the proto-Earth] motivated by the study of dynamics leading to the infalls. This is only one piece in the overall model of the multiple-impacts theory. The main limitations are in direct

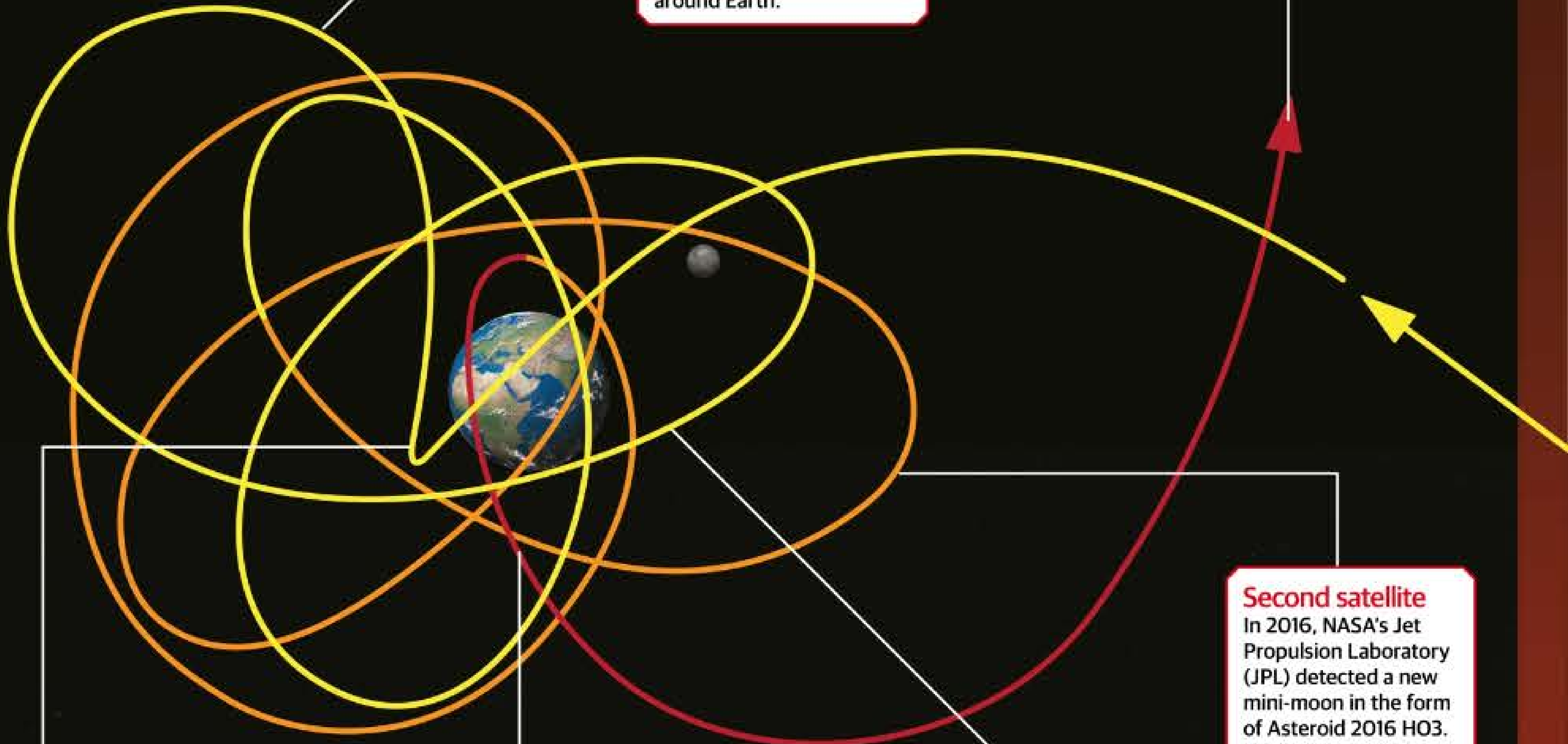
> "The current [giant-impact] paradigm is intrinsically incomplete and disconnected from the wider picture of terrestrial planet formation" **Prof Hagai Perets**

Left: Earth was battered by asteroids during its formation

Below: Falling mini-moons could be responsible for the formation of Earth's earliest continents

Earth's little moons

Our Solar System's planets have more than one moon - even our planet - on occasion



More than one moon
The Moon isn't our only satellite. Asteroids orbiting the Sun can temporarily become mini-moons following a complex path around Earth.

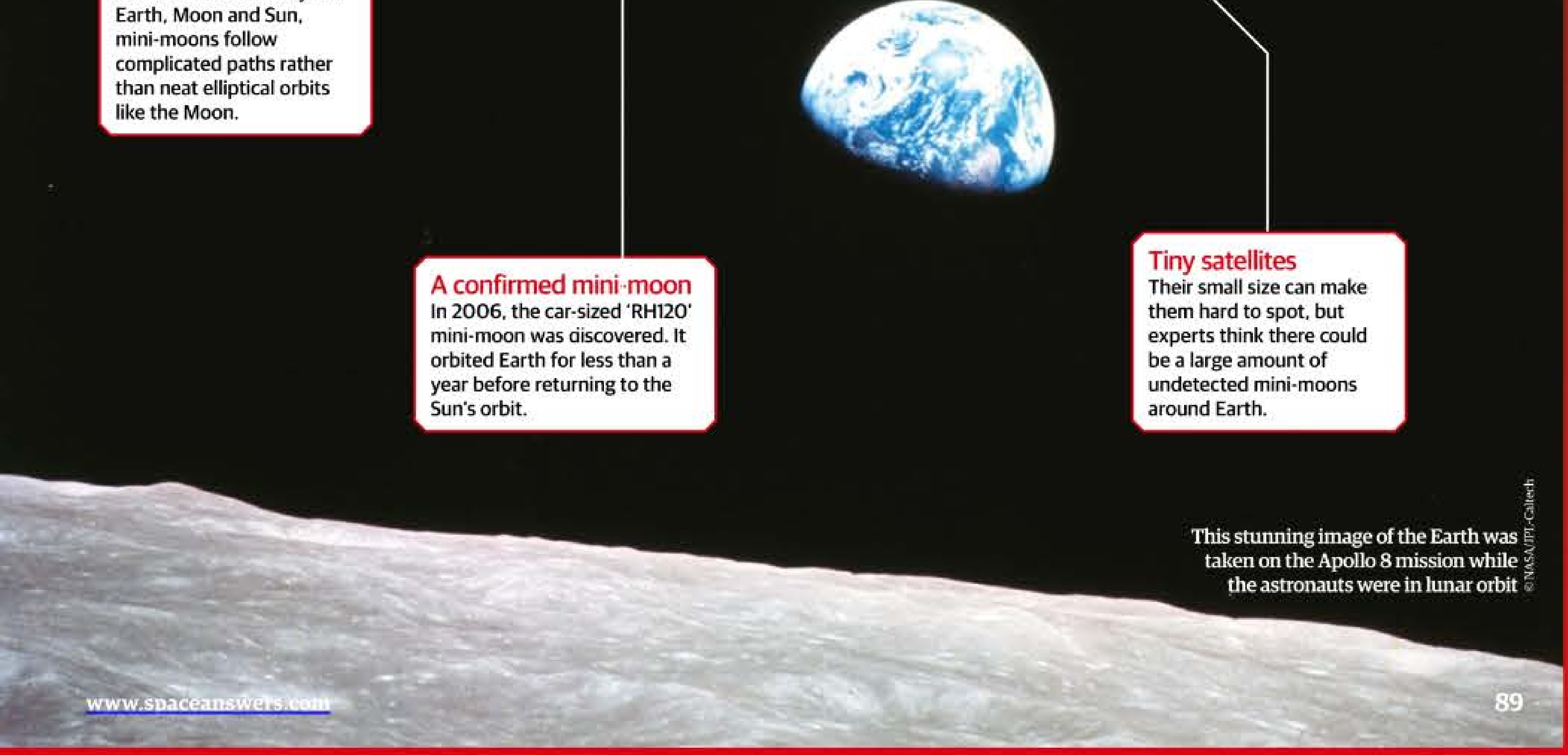
Temporary visitors
A typical mini-moon will orbit the Earth for around nine months, although some could stay in orbit for decades or more before being recaptured into orbit around the Sun.

Second satellite
In 2016, NASA's Jet Propulsion Laboratory (JPL) detected a new mini-moon in the form of Asteroid 2016 HO3. While technically in orbit around the Sun, the 'quasi-satellite' appears to circle Earth as well.

A complex journey
As they are tugged in different directions by the Earth, Moon and Sun, mini-moons follow complicated paths rather than neat elliptical orbits like the Moon.

A confirmed mini-moon
In 2006, the car-sized 'RH120' mini-moon was discovered. It orbited Earth for less than a year before returning to the Sun's orbit.

Tiny satellites
Their small size can make them hard to spot, but experts think there could be a large amount of undetected mini-moons around Earth.



This stunning image of the Earth was taken on the Apollo 8 mission while the astronauts were in lunar orbit

© NASA/JPL-Caltech

predictions that can still be observed today billions of years after the fact.

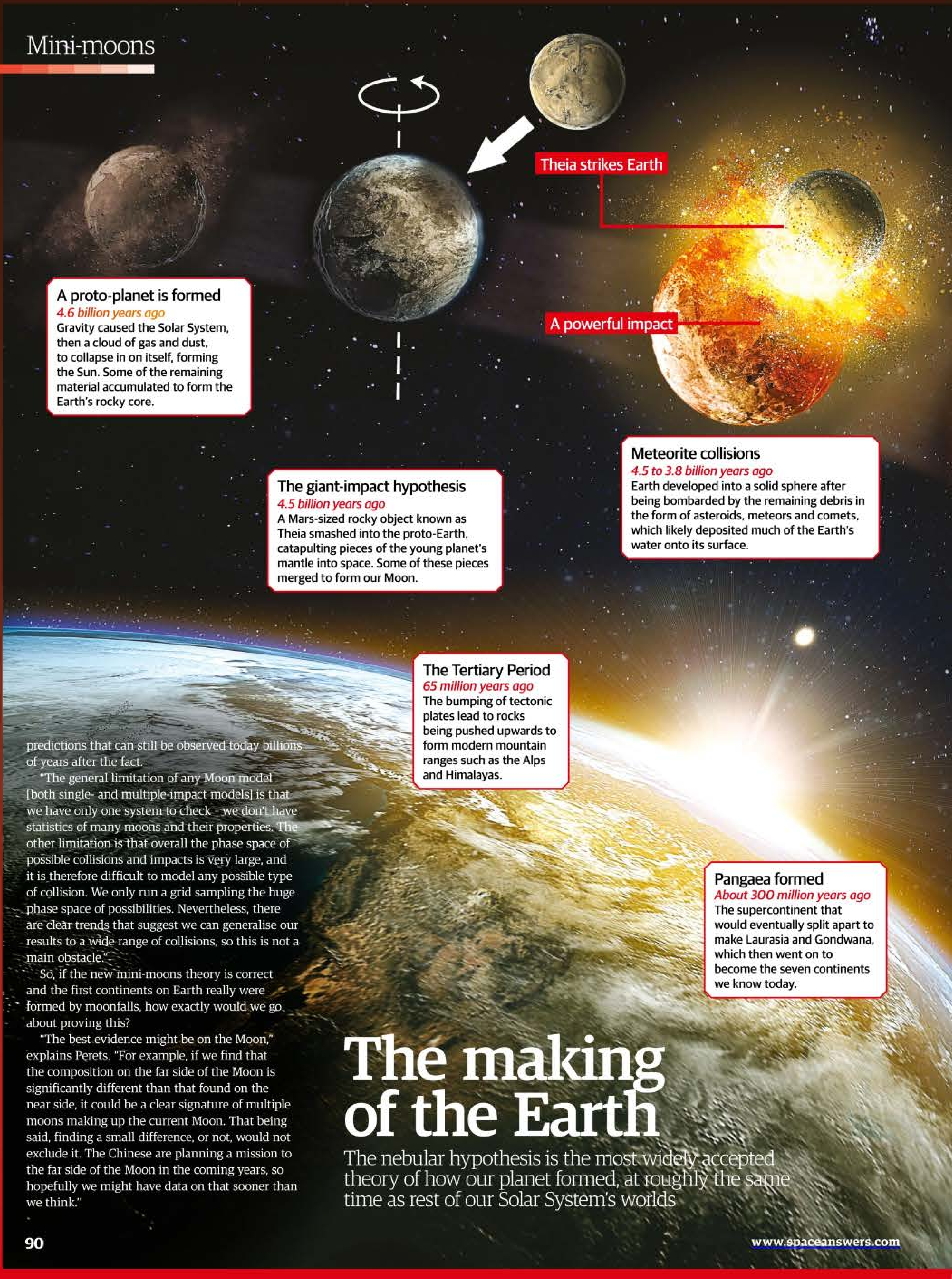
"The general limitation of any Moon model [both single- and multiple-impact models] is that we have only one system to check – we don't have statistics of many moons and their properties. The other limitation is that overall the phase space of possible collisions and impacts is very large, and it is therefore difficult to model any possible type of collision. We only run a grid sampling the huge phase space of possibilities. Nevertheless, there are clear trends that suggest we can generalise our results to a wide range of collisions, so this is not a main obstacle."

So, if the new mini-moons theory is correct and the first continents on Earth really were formed by moonfalls, how exactly would we go about proving this?

"The best evidence might be on the Moon," explains Perets. "For example, if we find that the composition on the far side of the Moon is significantly different than that found on the near side, it could be a clear signature of multiple moons making up the current Moon. That being said, finding a small difference, or not, would not exclude it. The Chinese are planning a mission to the far side of the Moon in the coming years, so hopefully we might have data on that sooner than we think."

The making of the Earth

The nebular hypothesis is the most widely accepted theory of how our planet formed, at roughly the same time as rest of our Solar System's worlds



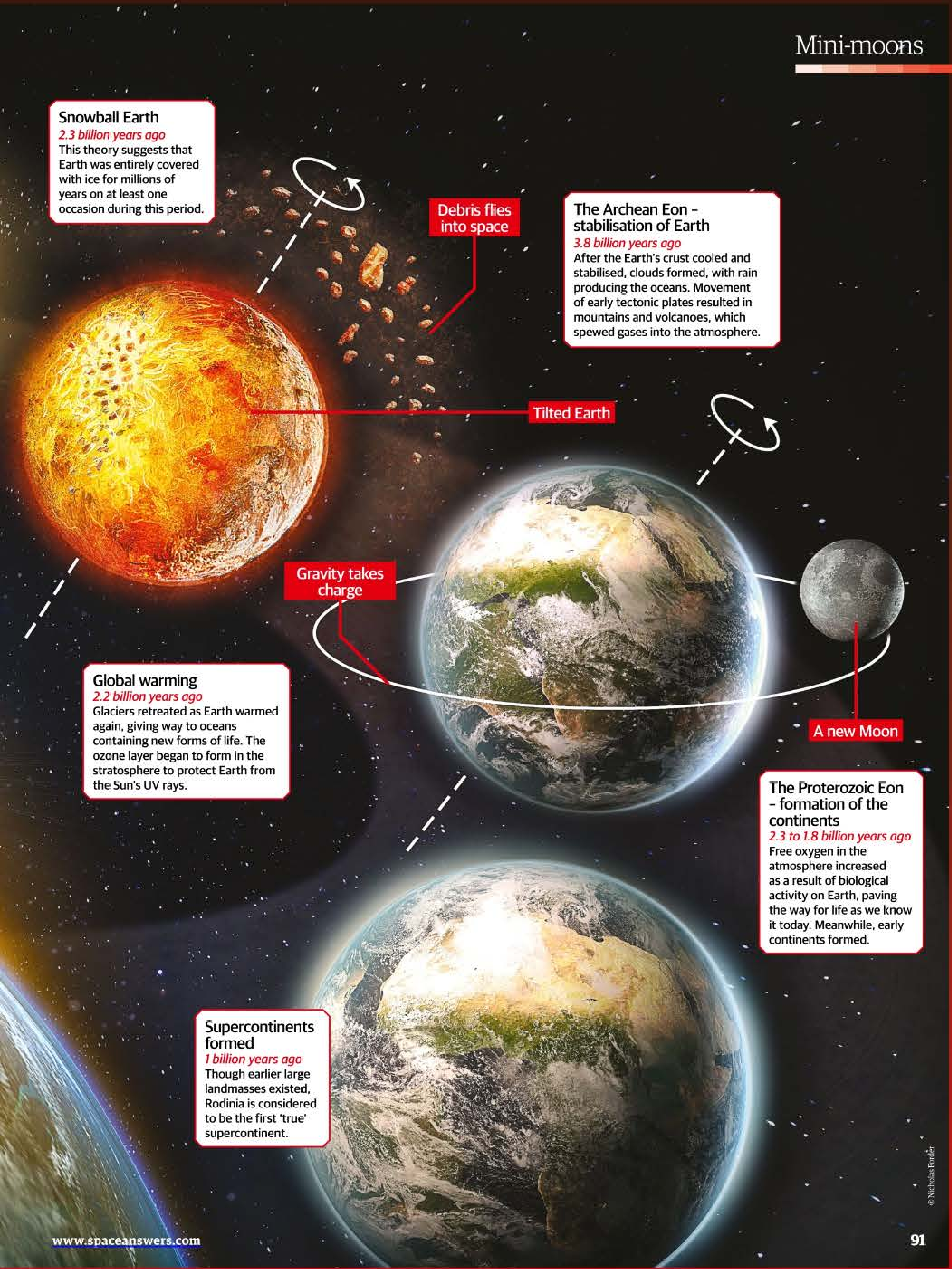
A proto-planet is formed
4.6 billion years ago
Gravity caused the Solar System, then a cloud of gas and dust, to collapse in on itself, forming the Sun. Some of the remaining material accumulated to form the Earth's rocky core.

The giant-impact hypothesis
4.5 billion years ago
A Mars-sized rocky object known as Theia smashed into the proto-Earth, catapulting pieces of the young planet's mantle into space. Some of these pieces merged to form our Moon.

Meteorite collisions
4.5 to 3.8 billion years ago
Earth developed into a solid sphere after being bombarded by the remaining debris in the form of asteroids, meteors and comets, which likely deposited much of the Earth's water onto its surface.

The Tertiary Period
65 million years ago
The bumping of tectonic plates lead to rocks being pushed upwards to form modern mountain ranges such as the Alps and Himalayas.

Pangaea formed
About 300 million years ago
The supercontinent that would eventually split apart to make Laurasia and Gondwana, which then went on to become the seven continents we know today.



Snowball Earth

2.3 billion years ago

This theory suggests that Earth was entirely covered with ice for millions of years on at least one occasion during this period.

The Archean Eon – stabilisation of Earth

3.8 billion years ago

After the Earth's crust cooled and stabilised, clouds formed, with rain producing the oceans. Movement of early tectonic plates resulted in mountains and volcanoes, which spewed gases into the atmosphere.

Global warming

2.2 billion years ago

Glaciers retreated as Earth warmed again, giving way to oceans containing new forms of life. The ozone layer began to form in the stratosphere to protect Earth from the Sun's UV rays.

The Proterozoic Eon – formation of the continents

2.3 to 1.8 billion years ago

Free oxygen in the atmosphere increased as a result of biological activity on Earth, paving the way for life as we know it today. Meanwhile, early continents formed.

Supercontinents formed

1 billion years ago

Though earlier large landmasses existed, Rodinia is considered to be the first 'true' supercontinent.

© Nicholas Forder

In May, the China National Space Administration (CNSA) launched a relay satellite which paves the way for this historic mission to the far side of the Moon. The satellite will provide a way for an upcoming lunar rover to communicate with Earth. Because the Moon is tidally locked to Earth we only ever see its near side, which is where all of the Apollo lunar landings were made. If successful, China's Chang'e 4 robotic orbiter-lander-rover would be the first spacecraft to ever touch down on the Moon's far side. The mission is currently scheduled for launch in December 2018, so new insights on the Moon formation theory could possibly be gleaned as early as next year.

The idea of impacts leading to the formation of topographic features on planets' surfaces isn't new. The latter stages of planet formation are thought to be characterised by extremely violent, catastrophic collisions, and features such as mountains can be seen on planets throughout the Solar System. But some experts disagree that the falling mini-moons would have formed any such features on Earth.

UCLA researchers Paul Warren, Edward Young and Issaku Kohl. Young is holding a sample of a rock from the Moon which backs up the giant-impact hypothesis

© Christelle Snow/UCLA

A concept drawing of early Earth depicts it battered by falling debris in the forms of asteroids, meteors and comets

> "Understanding the formation of the Moon can provide insights on the environment of the early Solar System and help us understand satellite formation"
> **Raluca Rufu**

As the Earth took around 100 million years to cool from molten magma into a solid sphere, it is questionable whether mini-moons falling during that time would have left any mark on the molten planet. However, the researchers argue that the moonlets would have struck Earth after much of the planet had solidified into a crust and that the impacts would have been gentle enough to remain on the surface, rather than smash through.

While not yet a conclusive argument, the idea of multiple, large-scale strikes on Earth producing a series of mini moonlets which then rained down on Earth to create the planet's landforms is certainly a compelling alternative to the currently accepted theory. But why is this idea so important?

"The latter stages of accretion, named the giant-impact phase, set the final architecture of the Solar System, and the composition of the final planets and their satellites," explains Rufu. "Understanding the formation of the Moon can provide insights on the environment of the early Solar System and it may help us understand whether satellite formation in general is abundant or whether it requires unique impact conditions.

"Moreover, due to its large size, the Moon stabilises Earth's tilt and provides a somewhat stable climate for life to evolve. If detecting exo-moons [satellites that orbit planets in other satellite systems] will be possible in the near future, then it may be more beneficial to look for life around planets with large satellites. Of course, this is somewhat speculative, as we know of only one planet that harbours life and it happens to have a large satellite."

A better understanding of the impacts that shaped the evolution of Earth could give us vital insights into how life-bearing planets form. In turn, this could help us track down potentially habitable planets in future, and maybe even ensure the endurance of the human race for generations to come. So, if the new theory is correct, mini-moons may well have shaped not only our past, but also our distant future.

SPACE STORMS

Storms come in all shapes, sizes and degrees of destruction throughout space, but what can they tell us about our Solar System? ***Written by Lee Cavendish***

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© Tobias Roetsch

The Solar System can be a cruel and unforgiving place, with storms that make Hurricane Irma look like a light breeze. Excluding solar space storms, which are bursts of highly energetic particles permeating circumsolar space, there are several worlds in the Solar System that wreak havoc from within.

From the Coronal Mass Ejections of the Sun to the rapid stormy winds of Neptune, the Solar System is full of extreme weather that rains trouble in one form or another. These storms not only cause a wonderful spectacle to observe from afar, but they can tell a different and more comprehensive story about the atmospheric and weathering conditions of a different planet or moon.

Sun

Earth radii: 109.2x
Earth masses: 333,060x
Atmosphere composition: Corona: highly-energetic and ionised particles (plasma)
Wind speeds: Ranging from 300 to 800 kilometres (186 to 497 miles) per second

Venus

Earth radii: 0.95x
Earth masses: 0.81x
Atmosphere composition: Carbon dioxide, nitrogen and sulphuric acid droplets
Wind speeds: 0.11 kilometres (0.07 miles) per second
Distance from Sun: 0.72 AU*

Earth

Earth radii: 1.0x
Earth masses: 1.0x
Atmosphere composition: Primarily nitrogen and oxygen
Wind speeds: Average of 0.005 kilometres (0.003 miles) per second
Distance from Sun: 1.0 AU

Mars

Radius: 0.53x
Mass: 0.11x
Atmosphere composition: Mostly carbon dioxide, nitrogen and argon
Wind speeds: Average of 0.01 kilometres (0.006 miles) per second
Distance from Sun: 1.52 AU

Jupiter

Earth radii: 10.97x
Earth masses: 317.83x
Atmosphere composition: Hydrogen, helium, water, ammonia and methane
Wind speeds: Up to 0.19 kilometres (0.12 miles) per second
Distance from Sun: 5.20 AU

Saturn

Earth radii: 9.14x
Earth masses: 95.16x
Atmosphere composition: Hydrogen, helium, methane and ammonia
Wind speeds: 0.5 kilometres (0.31 miles) per second
Distance from Sun: 9.54 AU

Titan

Earth radii: 0.40x
Earth masses: 0.0225x
Atmosphere composition: Nitrogen, methane, ammonia, argon and ethane
Wind speeds: 0.12 kilometres (0.075 miles) per second
Distance from Sun: 9.54 AU

Uranus

Earth radii: 3.98x
Earth masses: 14.5x
Atmosphere composition: Hydrogen, helium, methane, ammonia and water
Wind speeds: 0.25 kilometres (0.16 miles) per second
Distance from Sun: 19.18 AU

Neptune

Earth radii: 3.86x
Earth masses: 17.15x
Atmosphere composition: Hydrogen, helium, methane, ammonia and water
Wind speeds: 0.67 kilometres (0.42 miles) per second
Distance from Sun: 30.06 AU

*1 AU = Astronomical Unit = 149,597,870.7 kilometres

Sun

The Sun, the centrepiece of our entire Solar System, doesn't exhibit the same type of storms that we experience here on Earth. Instead, it expels dangerous amounts of energetic particles that cause space storms, which disrupt space weather.

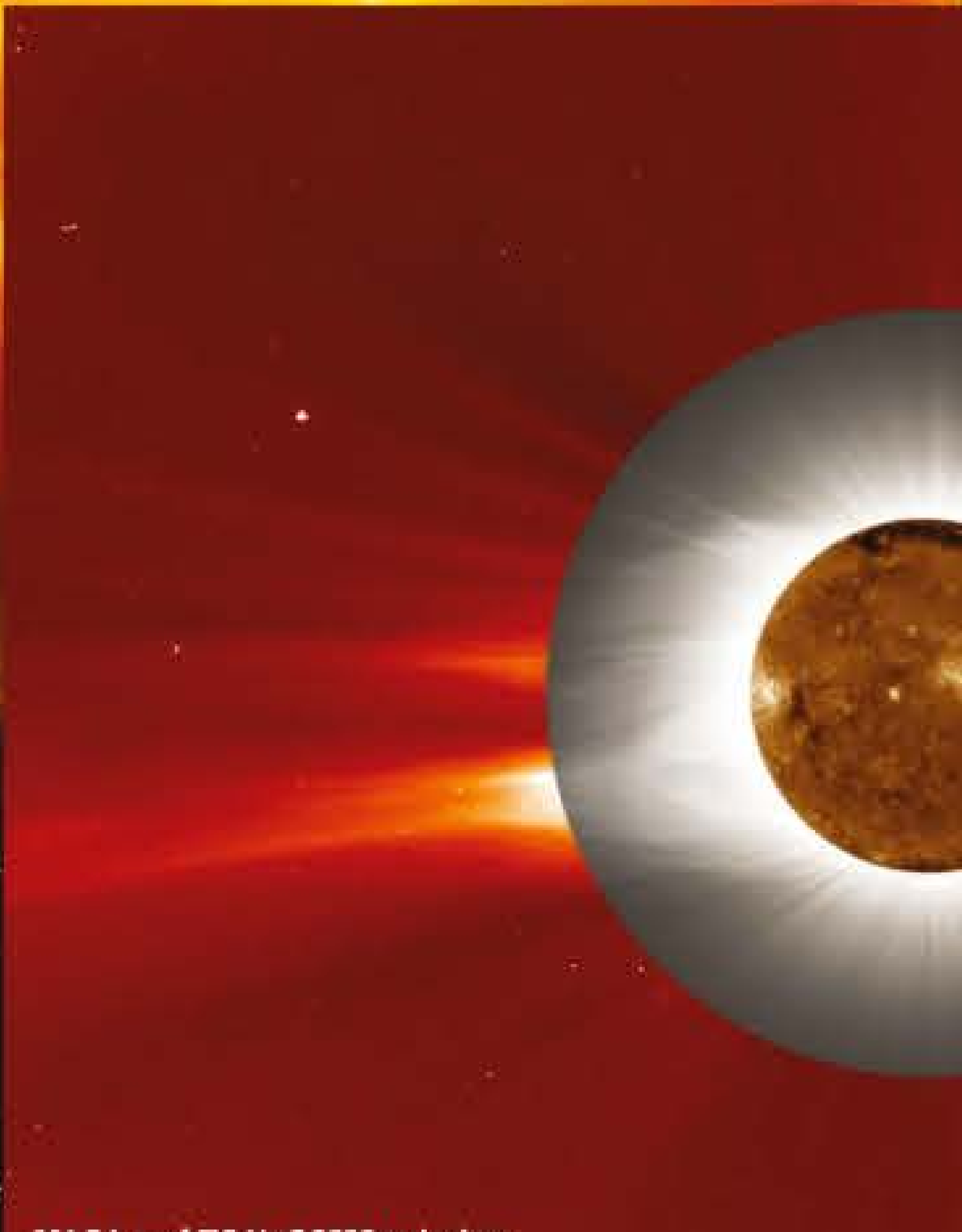
One type of solar explosion – a Coronal Mass Ejection (CME) – jettisons matter from the Sun's corona - the hottest, outermost part of its atmosphere. These expulsions rain down upon everything in the Solar System, affecting any spacecraft or planet in its way as it makes its way towards interstellar space. Yet, these storms shower Earth with the electrons that create the aurora.

What drives these CMEs is a question that astronomers are still trying to answer, particularly Dr Bernhard Fleck, who is the project scientist and mission manager of NASA and ESA's Solar and Heliospheric Observatory (SOHO). "CMEs are the most massive, largest and most energetic explosion events in the Solar System, so they are extremely interesting to study," Fleck tells **All About Space**. "How do they happen? Why do they happen? What drives them? What accelerates them? What heats the plasma? All these questions are fundamental scientific questions."

One of those questions can be answered, and that's what drives them. The answer to this is the Sun's magnetic field. The magnetic field of the Sun cannot be physically observed, but we can measure its strength based on its interaction with surrounding particles. As famous experimental physicist Robert Leighton once said: "If the Sun didn't have a magnetic field, it would be as boring a star as many astronomers believe it is."

But then on 14 October 2014, SOHO watched a spectacular CME escape the clutches of the Sun and accelerate into the cosmos. This CME went on to be detected by ten spacecraft, ranging from ESA's Venus Express all the way to NASA's Voyager 2. "It's very interesting to observe an event like this with so many spacecraft because it gives us a chance to study CMEs not just close to the Sun, or past Earth, but how they develop further out into the heliosphere," says Fleck.

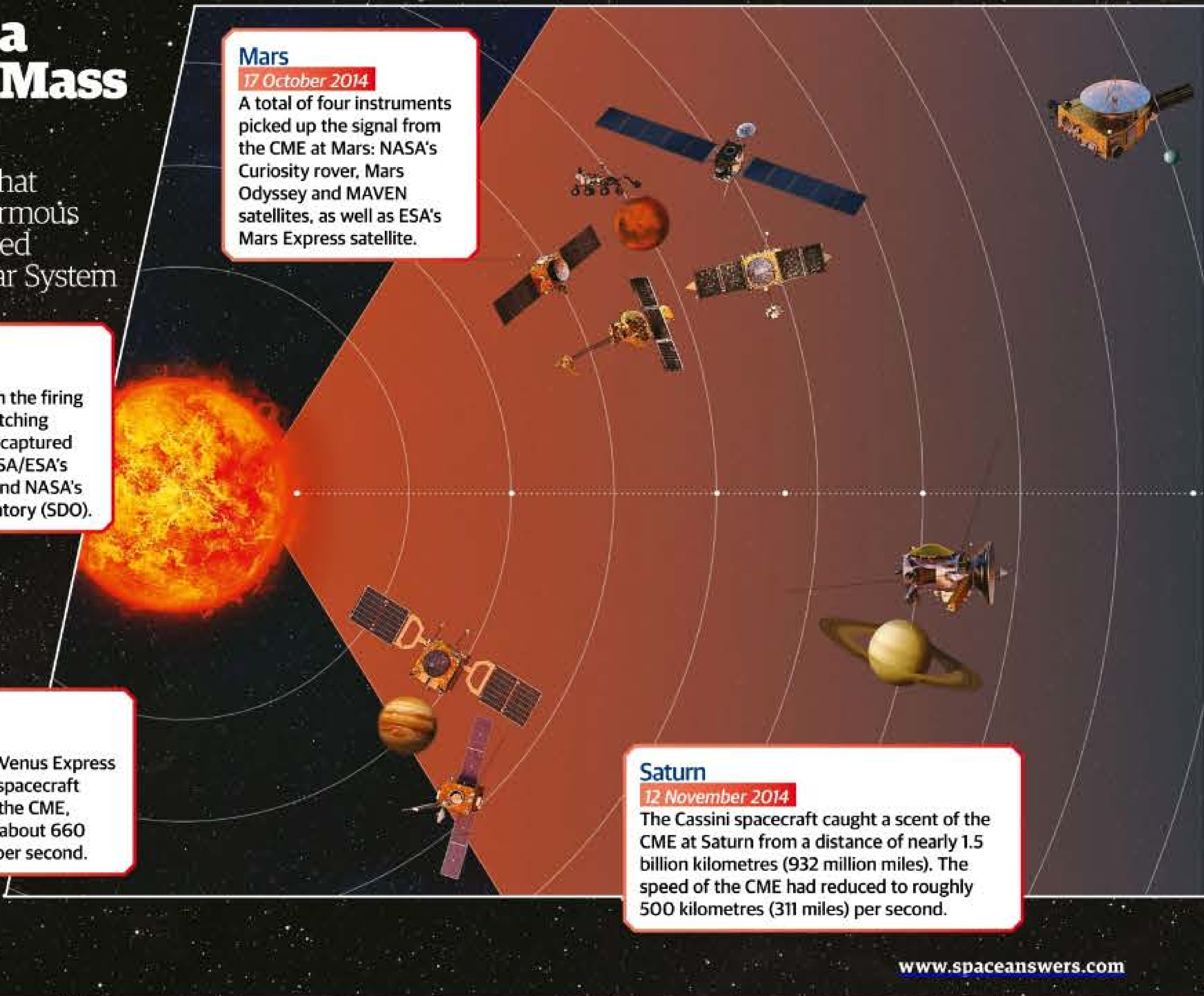
> "CMEs are the most energetic explosion events in the Solar System" **Dr Bernhard Fleck**



NASA and ESA's SOHO mission extensively studies the Sun and its scorching corona

Eyes on a Coronal Mass Ejection

The spacecraft that detected an enormous CME as it travelled through the Solar System



Earth

14 October 2014

Although Earth wasn't in the firing line of the CME, Sun-watching satellites close to home captured the event, including NASA/ESA's SOHO, ESA's PROBA-2 and NASA's Solar Dynamics Observatory (SDO).

Venus

16 October 2014

A few days after, ESA's Venus Express and NASA's STEREO-A spacecraft picked up the signal of the CME, travelling at a speed of about 660 kilometres (410 miles) per second.

Mars

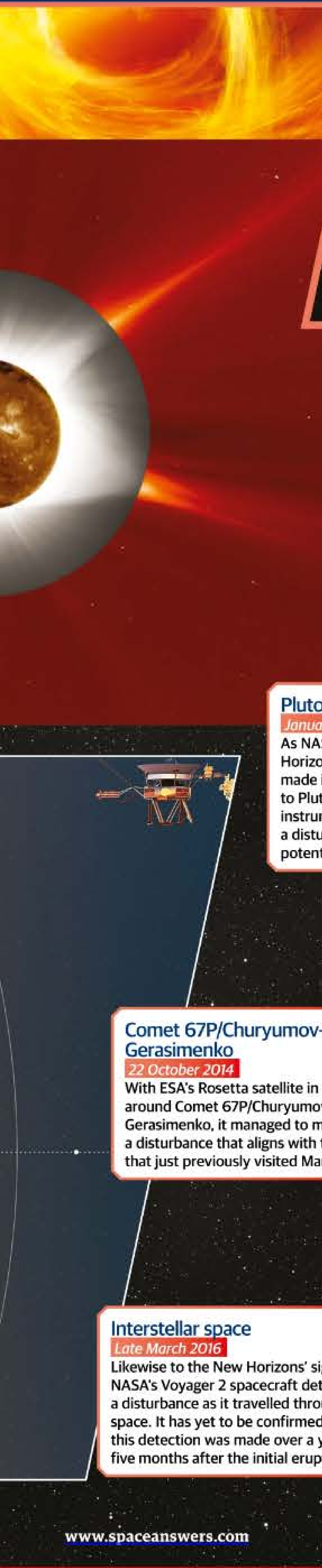
17 October 2014

A total of four instruments picked up the signal from the CME at Mars: NASA's Curiosity rover, Mars Odyssey and MAVEN satellites, as well as ESA's Mars Express satellite.

Saturn

12 November 2014

The Cassini spacecraft caught a scent of the CME at Saturn from a distance of nearly 1.5 billion kilometres (932 million miles). The speed of the CME had reduced to roughly 500 kilometres (311 miles) per second.



Pluto
January 2015
As NASA's New Horizons' spacecraft made its approach to Pluto, its onboard instruments picked up a disturbance. This was potentially the CME.

Comet 67P/Churyumov-Gerasimenko
22 October 2014
With ESA's Rosetta satellite in orbit around Comet 67P/Churyumov-Gerasimenko, it managed to measure a disturbance that aligns with the CME that just previously visited Mars.

Interstellar space
Late March 2016
Likewise to the New Horizons' signal, NASA's Voyager 2 spacecraft detected a disturbance as it travelled through space. It has yet to be confirmed, but this detection was made over a year and five months after the initial eruption.

Hurricane Irma was a Category 5 hurricane that caused catastrophic damage in September 2017

Earth The first-hand storm experience

By looking at the eight balls of rock and gas orbiting the Sun, a range of storms have been observed. These storms arise from disruptions within their different atmospheres, but only on Earth do we get first-hand experience of these events. Most are extremely unpleasant to experience, but what is learnt from them not only tells us a lot about our own planet, but this knowledge can also be applied to the atmospheres of the rest of our planetary family.

Storms can come in different forms, including tropical cyclones, thunderstorms, hailstorms and sandstorms. From studying the storms that arise on Earth we have been able to determine a number of factors responsible, including atmospheric and water cycles, temperatures, wind speeds and humidity.

The key ingredient for a tropical cyclone on Earth is warm ocean water. Throw in a sprinkle of high-speed winds and this can bring about a hurricane, typhoon or tornado. As the warm ocean water evaporates and condenses into clouds higher in the Earth's atmosphere, condensation releases more heat to create an unstable network of clouds. With the wind whisking up these clouds in this dangerous region, a tropical cyclone is born.

In a different, but fairly similar scenario thunderstorms can occur over someone's head. The same indifference between warm air evaporating and cold air higher up condensing causes hailstones in the process. These hailstones move within clouds and cause a negative charge that is collected at the base of the cloud. When the attraction between the negative clouds and Earth's positive surface becomes too much, magnificent flashes of thunder and lighting roar overhead.

In either case, scientists have been able to deduce how these arise, and it tells us a lot about the weather cycles and atmosphere on Earth. By seeing storms on other planets we can apply this same knowledge to tell us more about the troubling worlds we have yet to even visit.

© NASA; ESA; Nicholas Forder; Tobias Roetsch

Venus is the hottest planet in our Solar System – its thick atmosphere causes a runaway greenhouse effect

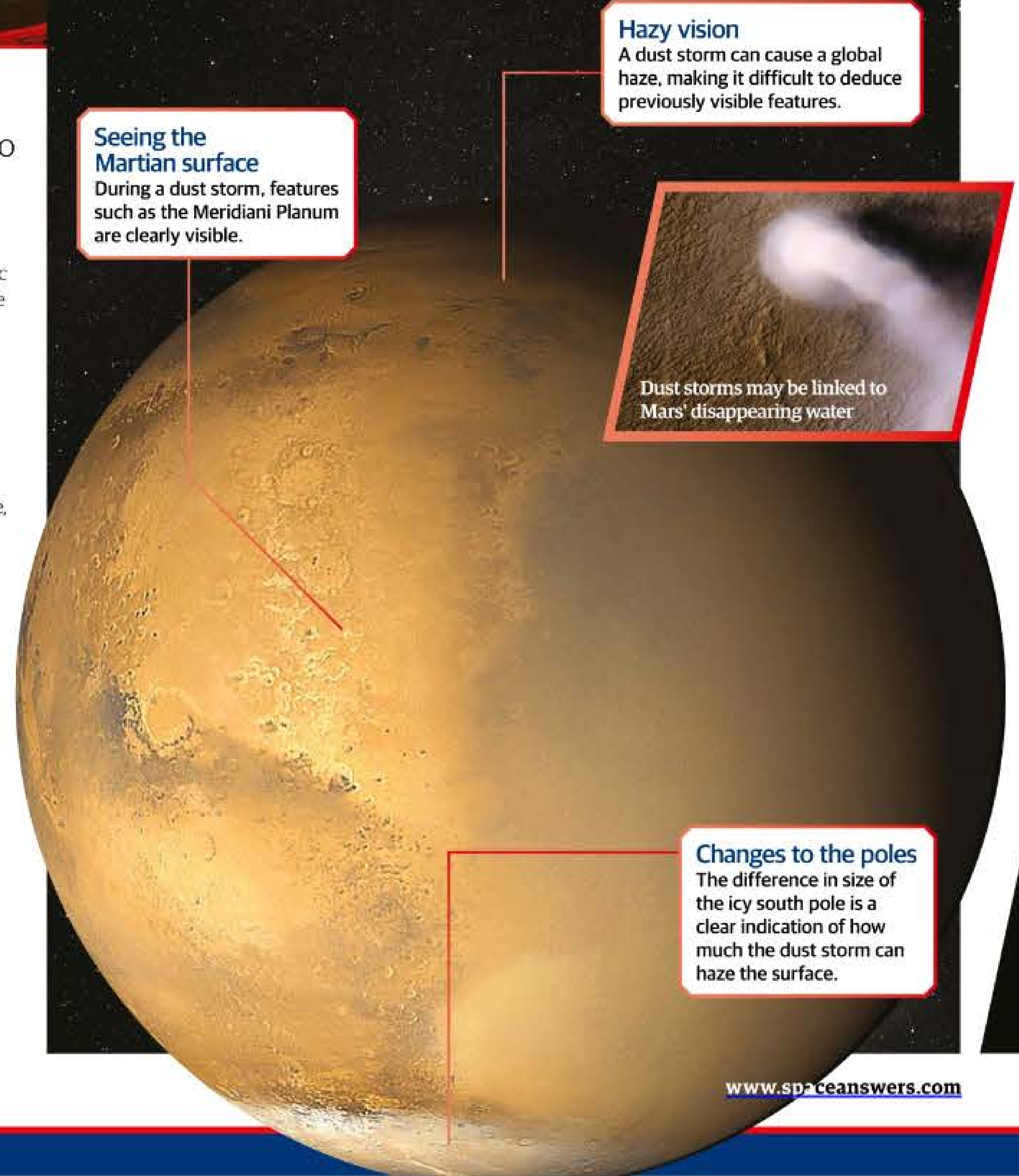
Mars

Although its atmosphere is thin, Mars can still summon an almighty dust storm

In order to whip up a good storm, you need a fairly sized atmosphere. Unfortunately for Mars, this is not the case. Its atmosphere is virtually non-existent when you compare it to the likes of its terrestrial siblings Earth and Venus. This means Mars doesn't experience the same kind of hurricanes, thunderstorms or even rain that we are familiar with. Despite that, another type of storm has been known to make an appearance on Mars, and that's a dust storm. Mars' atmosphere may be incredibly thin, but it produces enough wind to shake up the dust surface of Mars into a global dust storm.

While the dust storm spreads across the face of Mars, it can also cause atmospheric gas escape from the planet, contributing to the disappearance of an already-thin atmosphere. Dr Nicholas Heavens, research assistant professor of planetary science at Hampton University, Virginia, United States, tells **All About Space**, "Dust storms bring water vapour from near the surface to high altitudes where it dissociates into hydrogen and enriches the upper atmosphere in hydrogen that escapes Mars's atmosphere."

Heavens made it clear that these results can also tell us a lot about the past life of Mars, to a point where it had a more stable atmosphere and liquid water on the surface. "At some point, Mars probably was a warmer, wetter planet with a thicker atmosphere. Scientists are always looking for an explanation for where the water went," says Heavens. "The connection between dust storms and hydrogen escape can only be a partial explanation, because the mechanism requires a drier planet with a thin atmosphere to work well."



Hazy vision
A dust storm can cause a global haze, making it difficult to deduce previously visible features.

Seeing the Martian surface
During a dust storm, features such as the Meridiani Planum are clearly visible.

Dust storms may be linked to Mars' disappearing water

Changes to the poles
The difference in size of the icy south pole is a clear indication of how much the dust storm can haze the surface.

Venus

Earth's feverish sibling is home to vicious thunder and acidic rain

Venus is the closest thing there is to hell, with its scorching surface temperatures can reach 471 degrees Celsius (880 degrees Fahrenheit), sulphuric acid rain, active volcanism and thunderstorms. The European Space Agency's (ESA) first spacecraft to Venus – the Venus Express – was in orbit between 2006 and 2014, trying to peer through its thick atmosphere onto the surface lurking below.

In November 2007, the existence of thunderstorms on Venus was confirmed based on data taken by Venus Express' onboard magnetometer. This was fantastic news at the time, as it was the only planet other than Earth, Jupiter and Saturn able to generate lightning. On the original three planets it was known that interactions of water clouds produce thunder and lightning, but there is no such thing on Venus. The only explanation is that there is some form of electrical current build-up in the clouds of sulphuric acid, an exhilarating concept in terms of planetary sciences.

Based on what we know about how thunder and lightning form on Earth, planetary scientists say that instead of clumps of water ice bumping into each other, causing the negative electrical build-up, it is instead sulphuric acid-ice. A strange idea to think about, however, there is not enough evidence to disprove that theory at the moment. Only if another mission goes back to explore the boiling ball of rock that is Venus will astronomers and planetary scientists gather the data necessary to confirm or deny such an idea.

© NASA/JPL-Caltech; Tobias Roetsch

Jupiter

The Jovian atmosphere creates spectacularly enormous storms that are visible from Earth

Jupiter is a gaseous world that is renowned for its massive storms, the most famous of which is the Great Red Spot (GRS). After hundreds of years of observations, scientists are still uncovering secrets about this mysterious feature with NASA's Juno space probe.

"One of the most basic questions about Jupiter's Great Red Spot is: how deep are the roots?" says Scott Bolton, Juno's principal investigator from the Southwest Research Institute in San Antonio. "Juno data indicates that the Solar System's most famous storm is almost one-and-a-half Earths wide, and has roots that penetrate about 200 miles [322 kilometres] into the planet's atmosphere."

However, the iconic spot appears to be shrinking. About 150 years ago it was a size that could incorporate three Earths with room to spare. Whereas astronomers expected the Jovian winds to increase in speed as they contract (conservation of angular momentum), instead the storm actually stretches up, much like clay being shaped on a potter's wheel.

From Earth, we can only see Jupiter from an edge-on perspective. It wasn't until the Juno spacecraft got closer that astronomers could see the poles. What they saw was not what they were expecting. Not only do both poles consist of an enormous single central cyclone with several circumpolar cyclones, but they also appear to coexist in peace.

"These [polar] cyclones are huge, with winds speeds as great as 220 miles [354 kilometres] per hour," says Bolton. "These novel features seem to exist in harmony, close together and persistent. They are surprisingly different from the single storm pattern that the Cassini spacecraft measured at Saturn's poles."

There is still much to learn about Jupiter based on these complex and thought-provoking storms, but with Juno still orbiting Jupiter and gathering as much data as possible, there is much to learn about the dynamics of Jupiter. For instance, knowing that the wind speeds of the GRS haven't sped up with shrinkage, we can determine that the roots of the storms reach deeper than first thought. This helps astronomers determine the depth of the Jovian atmosphere.

> "The Solar System's most famous storm is almost one-and-a-half Earths wide" **Scott Bolton**

Check-up by Cassini
A passer-by in the form of NASA, ESA and ASI's Cassini-Huygens spacecraft captured the most amazing images of Jupiter and its GRS on its way to Saturn in December 2000.

Galileo's gander
NASA's Galileo spacecraft became the first craft to orbit an outer planet, taking this roughly true-colour image on 26 June 1996.

Here at Hubble
In 1996, the newly stabilised Hubble Space Telescope turned its optics to Jupiter in order to study the ever-changing nature of the GRS.

Juno's giant view
On 10 July 2017, NASA's Juno spacecraft flew over the GRS, and imaged it at about 13,917 kilometres (8,648 miles) above the clouds of Jupiter.

Voyager 1's view
Voyager 1 was the first spacecraft to visit Jupiter in February 1979. As it passed, Voyager snapped an image of the GRS and its surroundings.

Saturn

The ringed planet gives rise to a gigantic storm roughly every 30 years

Much like the Juno spacecraft at Jupiter, Saturn had its own visitor, NASA's Cassini spacecraft. For 13 years, Cassini watched over the ringed gas giant that is Saturn, and in that time the spacecraft returned unrivalled data and awe-inspiring images.

In December 2010, a dramatic storm arose on the face of Saturn, one of many that have occurred over the past decades, which astronomers have dubbed the 'Great White Spots'. The distinctive streaks of anarchy stretched across Saturn's surface and continued to grow. Cassini was able to watch the storm over this period, as lightning storms raged within and the winds reached speeds of up to 576 kilometres (358 miles) per hour.

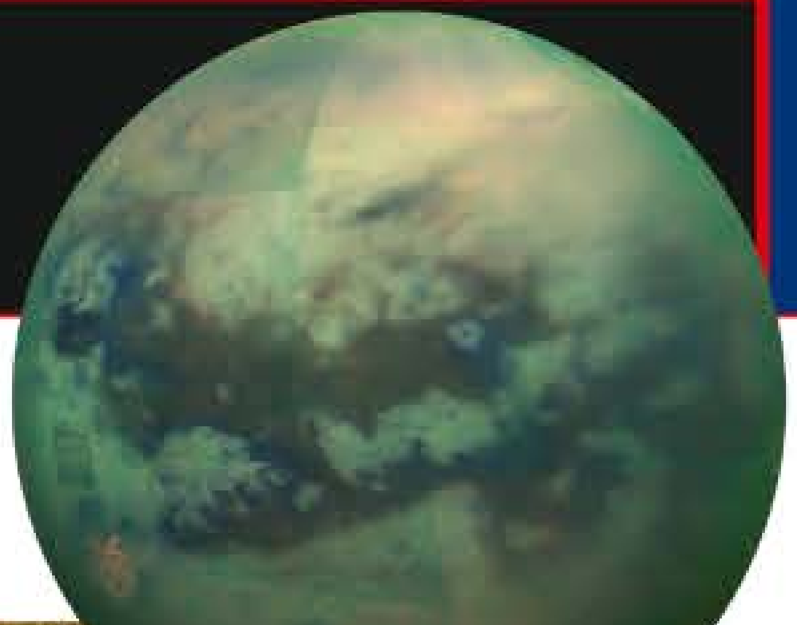
"With Cassini and ground-based data we were able to track the main vortex that was the source of the storm, as well as study the general circulation of the storm itself and to measure lightning coming from the storm," Dr Linda Spilker, project scientist of the Cassini mission explains to **All About Space**.

When asked about what these storms could tell us about Saturn's atmosphere, Spilker replied: "These events occur once every 30 years or so – once every Saturn orbit about the Sun – and release a tremendous amount of energy into the atmosphere."

As for how these storms arise, again it is not well understood. However, a mechanism has recently been suggested, which matches observations. This mechanism details how the cooling of the planet's upper atmosphere overpowers and suppresses the internal convection. Due to Saturn's extremely cold atmosphere, it takes roughly 30 years for the air to warm up and rise to create the thunderstorms.

Doesn't this sound familiar to thunderstorms on Earth? Although the atmospheres of the two planets are completely different - Earth having an atmosphere of primarily heavy molecules and Saturn having mostly hydrogen and helium - the occurrence of such an event revolves around similar mechanisms.

Cassini observed a lightning signal from deep in the planet's atmosphere in 2010



Titan

Saturn's largest moon has a thick atmosphere with rainstorms drenching the surface in hydrocarbons

Saturn's minor companion, Titan, is an interesting target for astronomers, as its surface it abundant in liquid methane and ethane, the building blocks for complex compounds like DNA. It is also the only known moon with a dense atmosphere, making it visually appear covered in an orange fog.

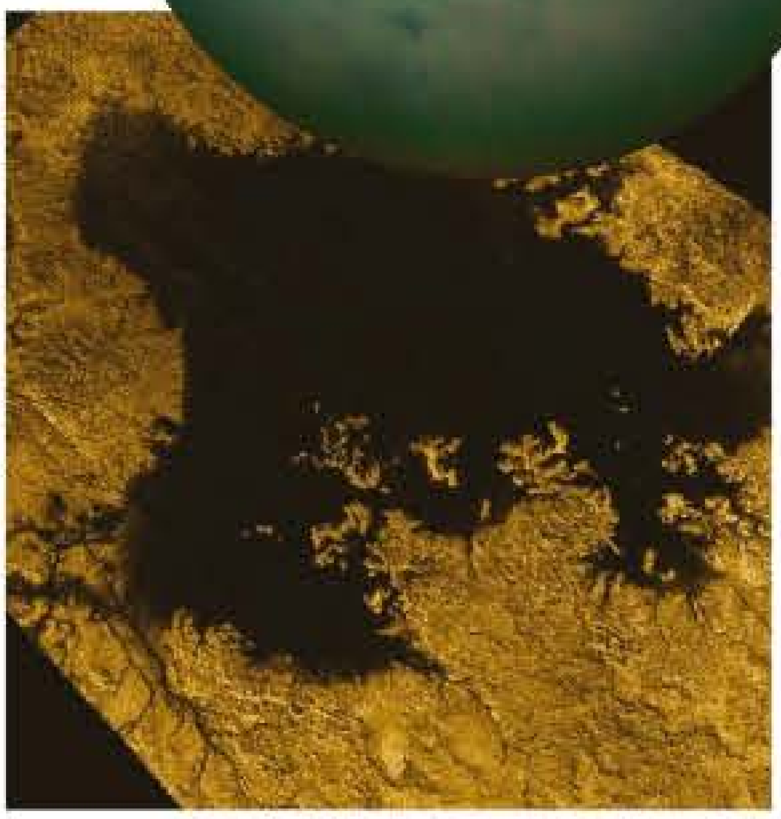
With the presence of a dense atmosphere and large quantities of liquid methane, a theory confirmed by NASA/ESA/ASI's Cassini-Huygens mission and a host of contributing scientists state that troublesome weather is bound to terrorise the surface of this distant moon.

"Cassini saw evidence for a giant methane rainstorm on Titan that wet part of the surface," Spilker explains. "We then watched that surface dry out over the next several months. We saw clouds and evidence of other storms as well."

"Storms on Titan are part of Titan's seasonal weather cycle and help us understand the weather on Titan. They also tell us about surface erosional processes," Spilker continues.

Erosional processes that sculpted out riverbeds, channels and dunes are relatable to those observed on Earth. For instance, Lake Poopó in Bolivia was once a majestic saline lake – the second-largest – but its now dried up, and what's left is a geological dent in the surface of Earth. These same types of 'dents' have been seen on the surface Titan, and this tells astronomers and planetary scientists a lot about weather processes on Titan.

There is a lot of talk about going back to Titan with NASA's proposed Dragonfly drone, and this would be able to fully investigate its environment. The organic chemistry, habitability, atmospheric and surface conditions could be studied in unprecedented detail, and this would provide valuable data is explaining how these storms occur on Saturn's largest moon.



Ligeia Mare is the second-largest known body of liquid on Titan

A recent infrared image of Uranus' storm has been overlaid on top of a Voyager 2 true-colour image.

The only spacecraft to visit the ice giants, Voyager 2, managed to image Neptune's Great Dark Spot in 1989.

The ice giants

Uranus and Neptune have storms that travel mysteriously quickly across their faces

The icy duo may seem dull from afar, but that is far from the case. Their blue surfaces may seem like inconspicuous balls of hydrogen, helium and traces of volatiles, but they exhibit some of the most extreme and violent storms in our Solar System.

In comparison to Uranus', and in particular Neptune's winds, Earth's winds are barely even noticeable. Uranus exhibits wind speeds of up to 900 kilometres (560 miles) per hour, but it's Neptune that holds the title of the 'Solar System's windiest world' with supersonic speeds of up to 2,414 kilometres (1,500 miles) per hour.

Back in 2012, astronomers used the telescopes at the Keck Observatory in Hawaii to observe the ice giant, Uranus, in near-infrared wavelengths. This revealed complex weather containing circulating clouds, massive hurricanes and an unusual swarm of convective features at its north pole.

As for Neptune, the most powerful storm that has been observed was the Great Dark Spot, which stirred much public interest during the Voyager 2 flyby in 1989. Since then, astronomers have primarily relied on the Hubble Space Telescope and other ground-based telescopes to watch out for discrepancies. Only last year, the Keck Observatory saw a troublemaker arise on Neptune in the form of a massive storm system stretching roughly 9,000 kilometres (5,592 miles) in length.

"This big vortex is sitting in a region where the air, overall, is subsiding rather than rising," says Professor Imke de Pater of UC Berkley's Astronomy Department. "Moreover, a long-lasting vortex right at the equator would be hard to explain physically."

Since weather is driven by the heat of the Sun, and sunlight is 400-times weaker at Uranus, and over 900-times weaker at Neptune, than at Earth, the solar energy driving these systems are a mystery. By studying storms such as these, astronomers are continuously gaining a clearer picture of what is powering these powerful winds from within, as the absence of solar energy is not enough. What is clear is that both atmospheres must operate very efficiently with very little energy squandered in order to maintain the drastic atmospheric variations required to summon these storms.

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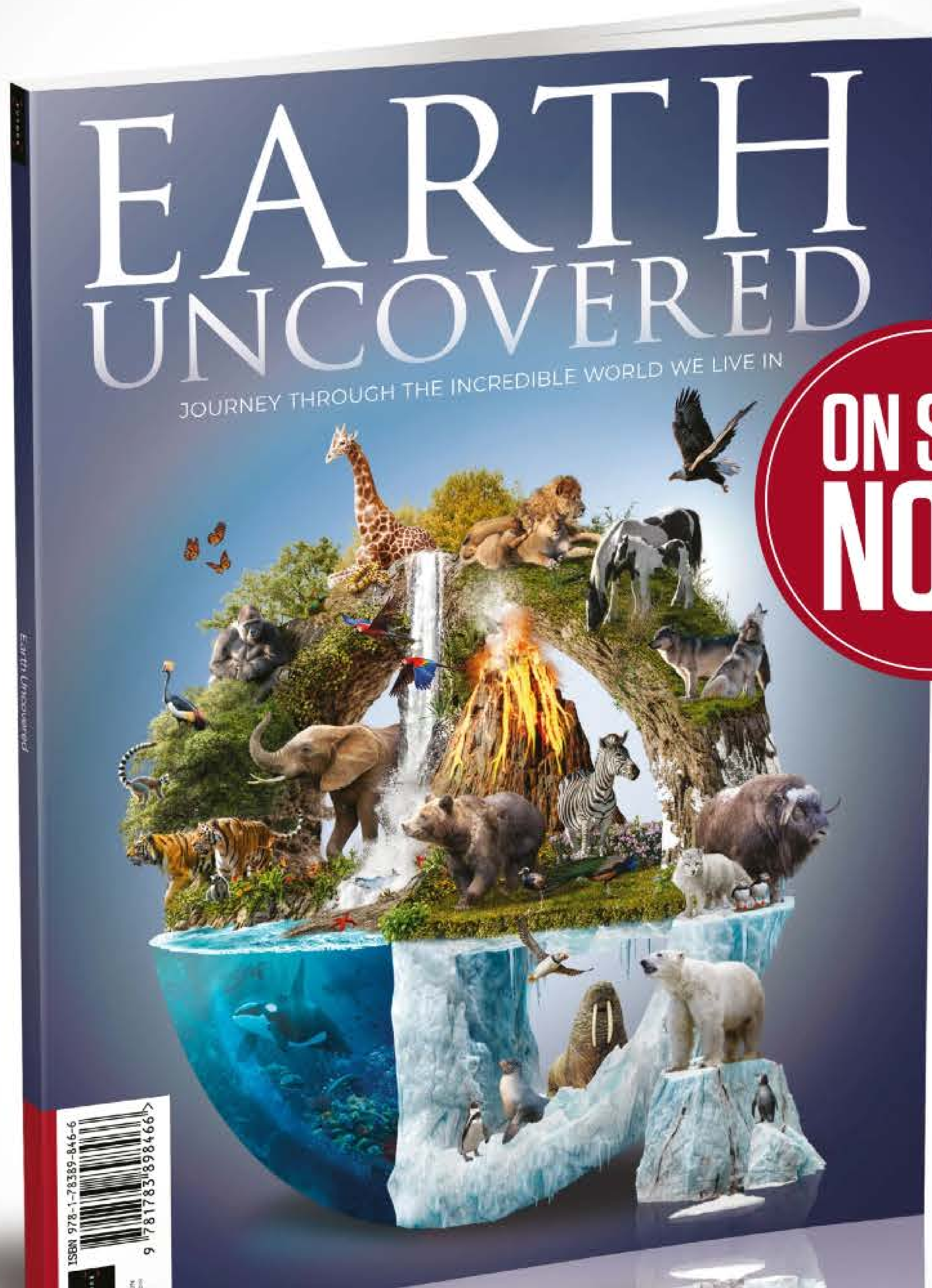

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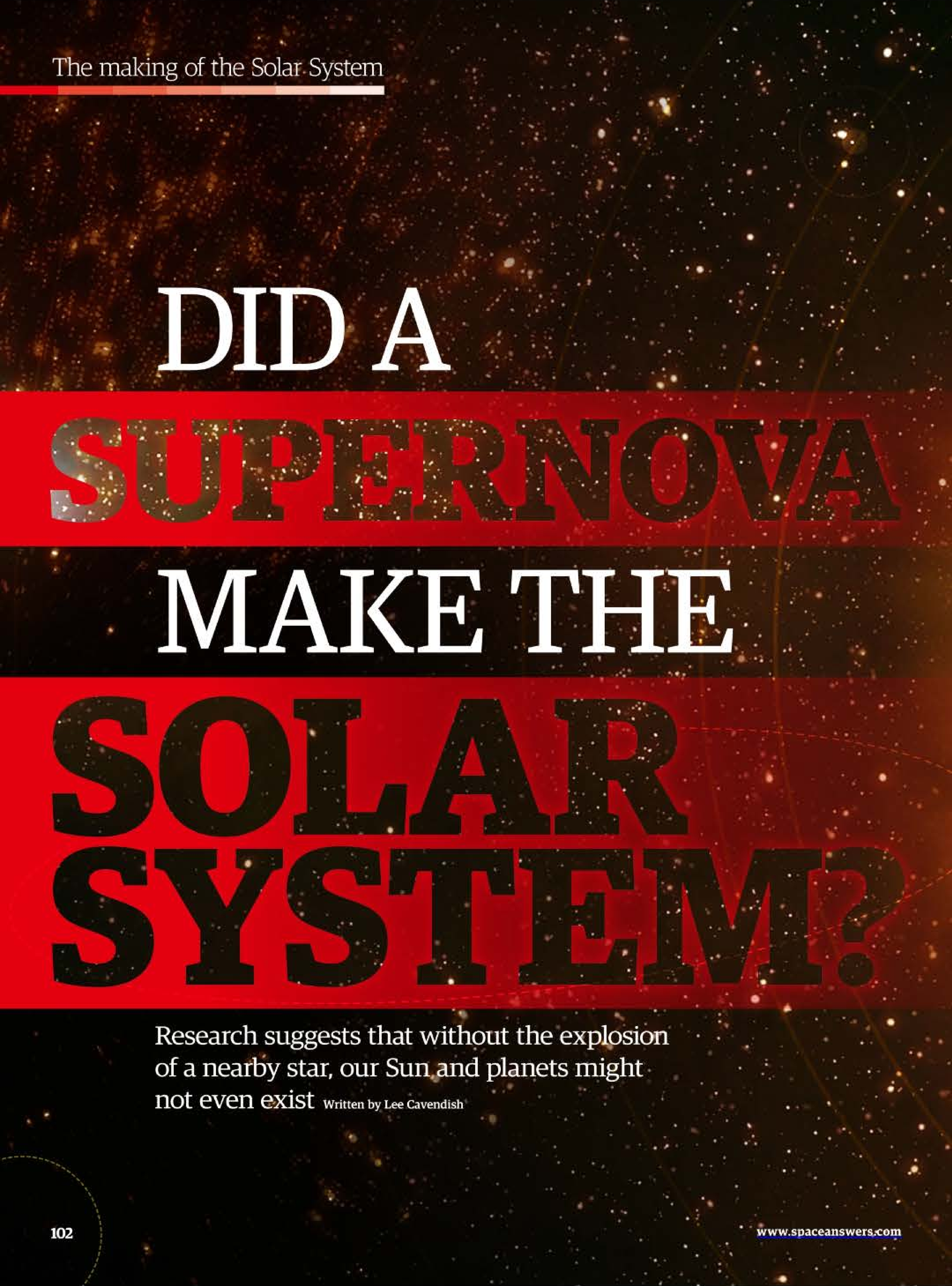
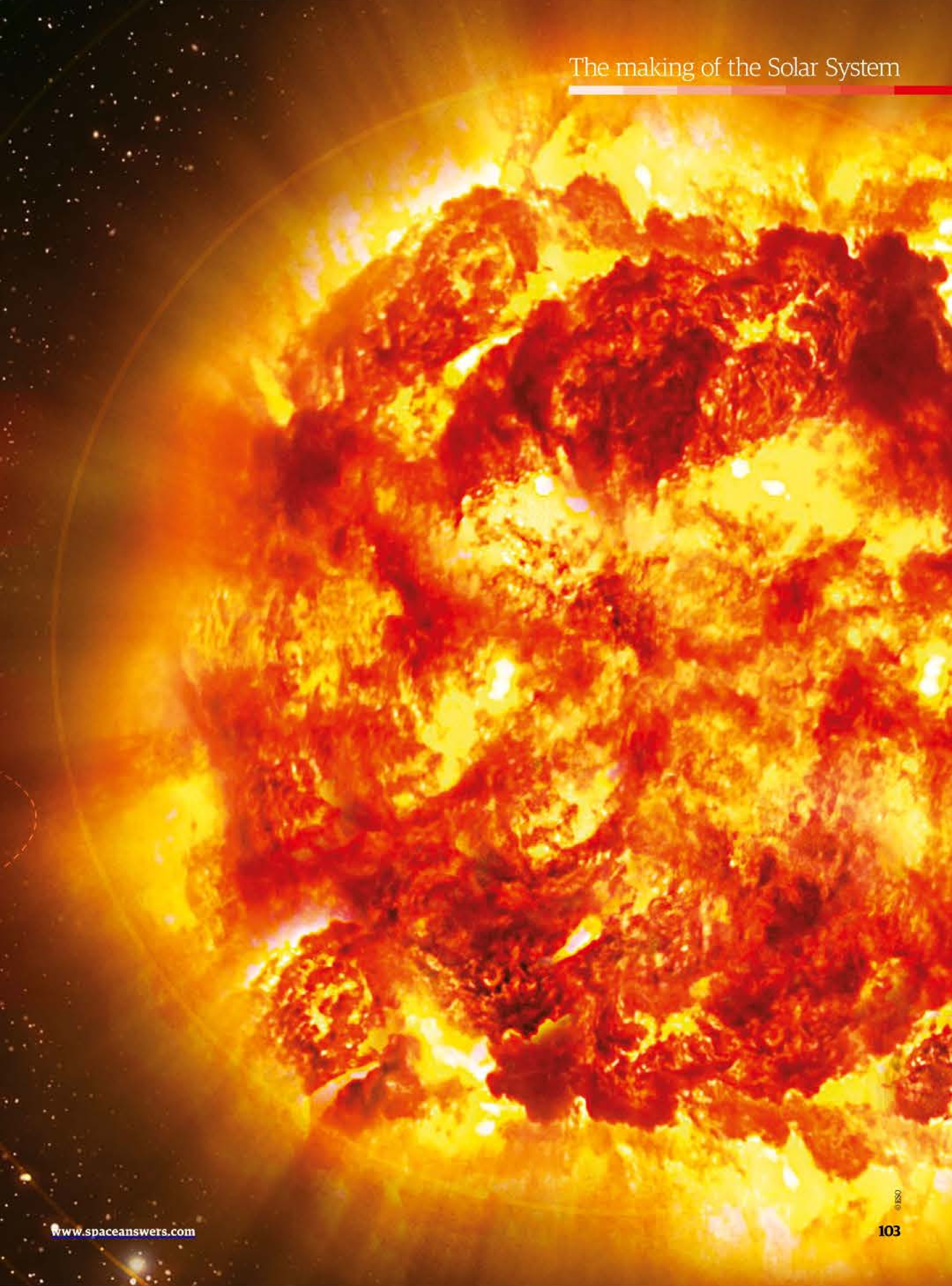


DID A SUPERNOVA MAKE THE SOLAR SYSTEM?

Research suggests that without the explosion of a nearby star, our Sun and planets might not even exist

Written by Lee Cavendish



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In the vast neighbourhood of stars that is our Milky Way, our home sits 27,000 light-years from the galactic centre in the 'Orion Arm'. Our Solar System is home to a main sequence star, eight incredibly varied planets, countless moons, dwarf planets and other objects we have become more accustomed to over the years.

The diversity across the Solar System presents a visual masterpiece. The question we should be asking - as we should with everything in the universe - is, "how did it get there?" This is a question that has perplexed scientists for decades when delving into the origins of the Solar System. No matter how many theories scientists come up with, they need to explain multiple complex aspects. For example, how do you explain the Sun being at the centre of all mass? Why did the planets form orbiting a level plane? But also, where did cosmic metals (any element heavier than helium) come from?

The leading theory for all of this is the 'Nebula Hypothesis'. This theorises that the Solar System began as a giant, diffuse cloud of gas (akin to the Orion Nebula), until an event occurred which caused its collapse 4.6 billion years ago. Continuous contraction then transformed the core of the cloud into a young, small star, also known as a protostar. While this happened, the surrounding material formed a disc that spun around the protostar, known as a protoplanetary disc. This protoplanetary disc contained material that had enough angular momentum to not fall into the protostar, which would have almost resembled Saturn and its rings, just on a much larger scale.

Roughly 10 million years later, the protostar had eaten enough of the surrounding gas to produce gigantic amounts of pressure in the core. The insane pressure increased the core temperature to the point where thermonuclear fusion finally began, ushering in the era of our main sequence star. Nonetheless, there was more construction to do: there was the formation of planets still to come.

Our planets all stem from the surrounding protoplanetary disc that revolved around our early Sun. This plane of gas swirling around the protostar began to cool, causing the gas to clump together - similar to how dust bunnies arise in a normal household. As these tiny clumps of rock travel around the disc, their tiny gravity is enough to contract more and more surrounding material, snowballing into clumps of sizes up to 200 metres.

The radioactive material is shown as blue in this supernova explosion. This is the material that got transferred to the Sun's primeval nebula

Further collisions between these bodies led to the formation of even larger planetesimals - much larger bodies with sizes around ten kilometres (6.2 miles) - which can also be thought of as baby planets. Continuous collisions caused perpetual expansion for the planetesimals at a rate of centimetres per year, particularly at one Astronomical Unit (AU) - the distance between the Sun and the Earth - where the rate of expansion was 15 centimetres per year. The planetesimals that could gather large amounts of mass became Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. The remaining debris that couldn't quite gather enough mass to make up a planet is what we now know as the moons, asteroids and comets.

This explains how we got our Sun, planets and remaining debris, but this still can't fully explain the presence of the primordial metallic elements. Due to this, astronomers are pointed in the direction of a supernova explosion as the 'starting pistol'. It is known that a supernova explosion occurs at the end of a star's life; at this stage the star has already synthesised an abundance of metals in an attempt to prolong its life. Once it can't synthesise any more, the gravitational compression of the star overpowers the radiation

> "No matter how many theories scientists come up with, they need to explain multiple complex aspects"

The Solar System was created 4.5 billion years ago. This is confirmed by meteorite analysis

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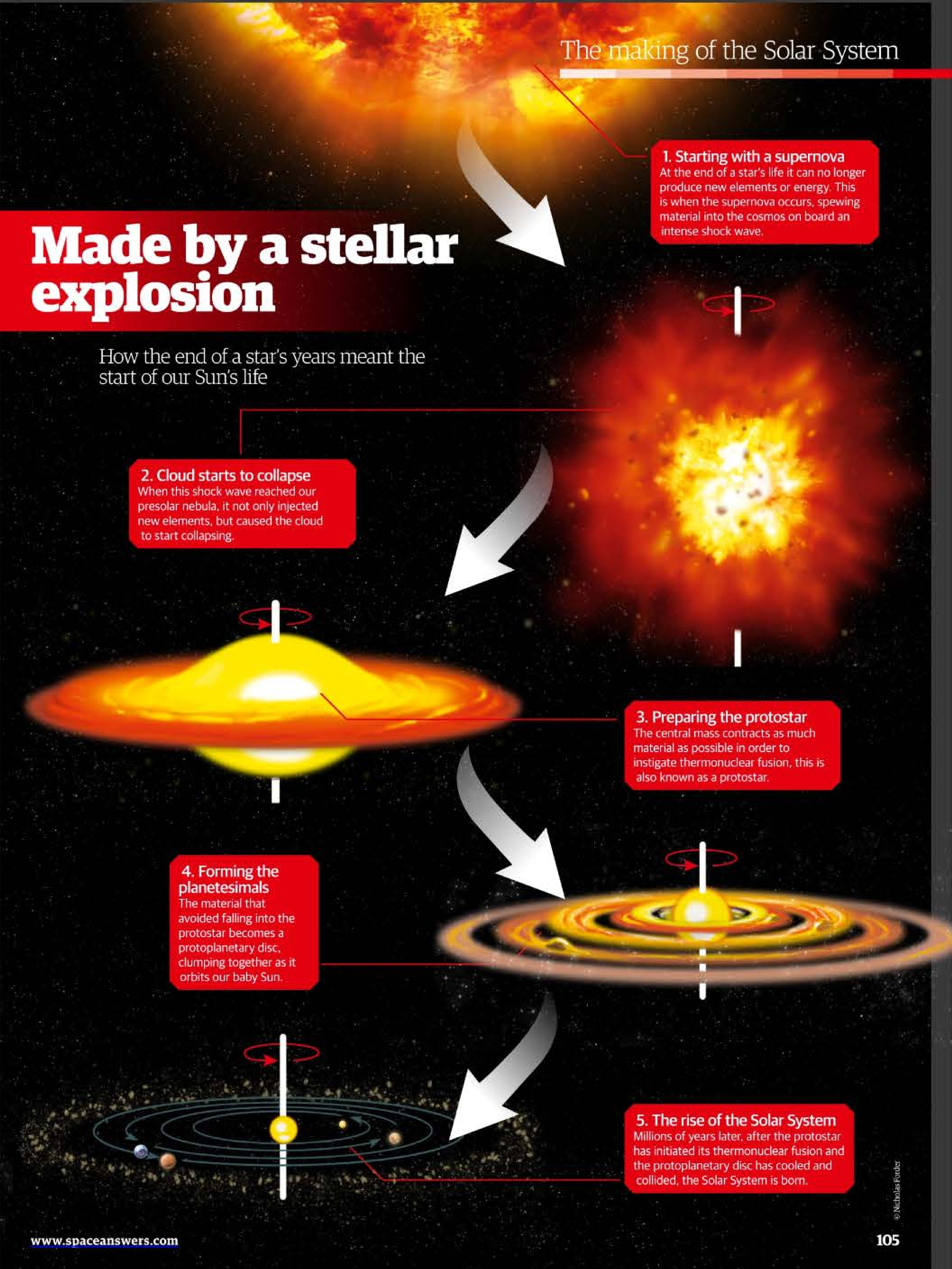
Made by a stellar explosion

How the end of a star's years meant the start of our Sun's life



1. Starting with a supernova
At the end of a star's life it can no longer produce new elements or energy. This is when the supernova occurs, spewing material into the cosmos on board an intense shock wave.

2. Cloud starts to collapse
When this shock wave reached our presolar nebula, it not only injected new elements, but caused the cloud to start collapsing.

3. Preparing the protostar
The central mass contracts as much material as possible in order to instigate thermonuclear fusion, this is also known as a protostar.

4. Forming the planetesimals
The material that avoided falling into the protostar becomes a protoplanetary disc, clumping together as it orbits our baby Sun.

5. The rise of the Solar System
Millions of years later, after the protostar has initiated its thermonuclear fusion and the protoplanetary disc has cooled and collided, the Solar System is born.

© Nicholas Forder

"Meteorites play a vital role in understanding the origins of our universe, as they are the oldest known objects in the Solar System"

to a spectacular explosion that casts its metallic elements into the cosmos. It is believed these elements ride the supernova shock wave through the cosmos until it interacts with another nebula, completing the stellar circle of life.

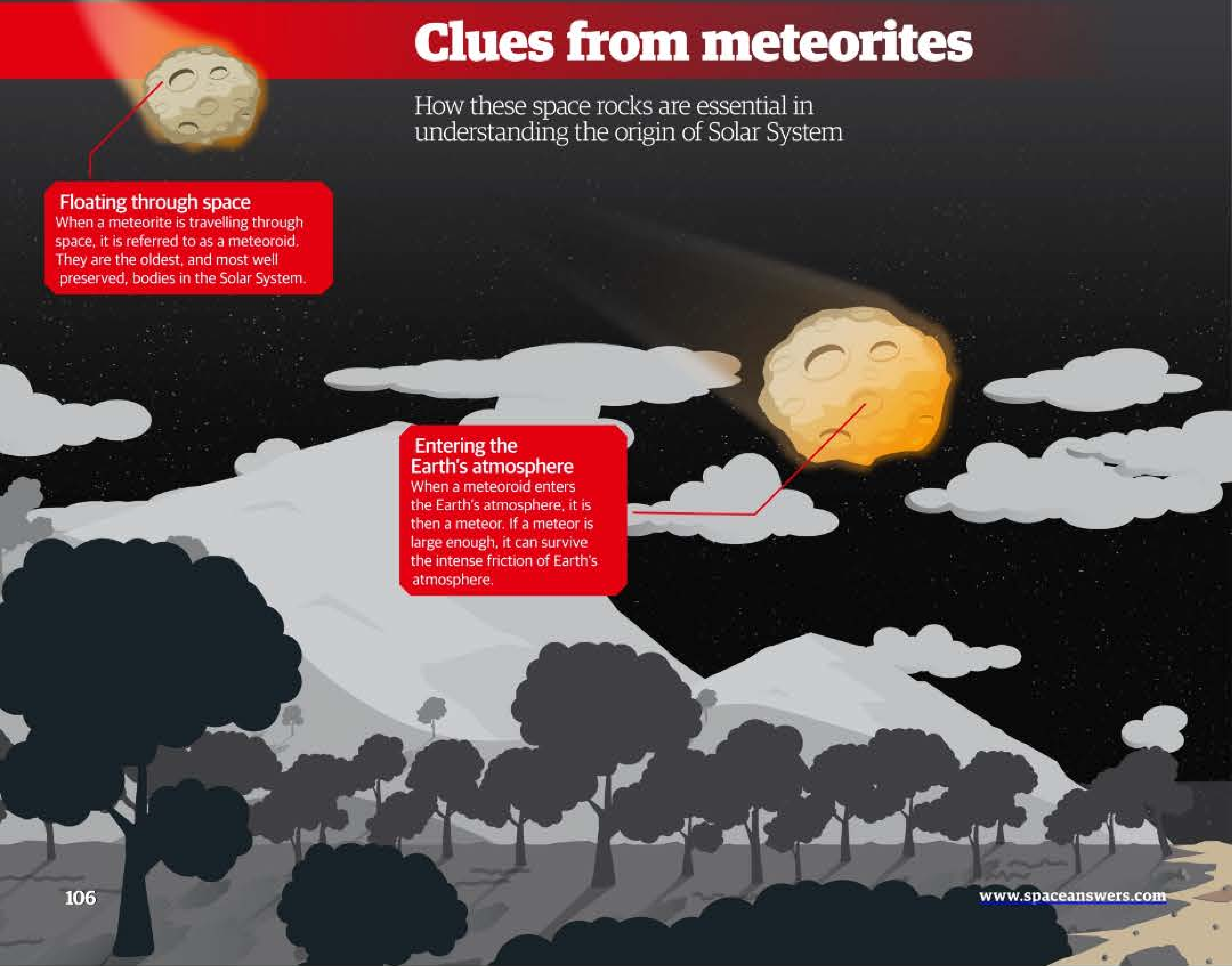
In the case of our solar nebula, a nearby supernova shock wave could have rattled our future home, as well as introducing a series of complex elements into the mix. Only recently have astronomers been able to provide evidence for such an event, and their evidence relies heavily on meteorite analysis. Meteorites are pieces of space rock that have landed on Earth. They play a vital role in understanding the origins of our universe, as they are the oldest known objects in the Solar System. The process that uncovers the age of an object is known as isotopic dating, or radioactive dating. This technique can be used to date all kinds of rocks.

When rocks are originally formed, they are filled to the brim with radioactive elements - which can also been called isotopes. These are elements that contain the same number of protons as a known element, but a different number of neutrons, making them unstable. To stabilise the element, the isotope must eject some of its matter, creating a completely new element. The time taken to form this new element is called the 'half-life'. By determining the half-life of elements in a rock, you can then infer the age of the rock. The most common example for this is Carbon-14 isotope dating. Unfortunately this is just for previously living things on Earth, meaning this method can only date objects within the last 50,000 years. This is why astronomers use meteorites to date objects millions, or even billions, of years old. In fact, the oldest known meteorite was discovered in north-west Africa in the form of a carbonaceous chondrite meteorite, later named NWA 2364. This meteorite was analysed to be 4.568-billion-years old, give or take 170,000 years. It was supposedly formed around the time when the first solids condensed in the protoplanetary disc.

Dr Alan Boss, of the Carnegie Institute of Science, recently published a new theory regarding the origins of the Solar System. This theory explains how a supernova not only produced a shock wave powerful enough to cause the collapse of our solar nebula, but how that shock wave also injected interstellar material which originated from the dying star. This theory is based on the analysis of meteorites, and their isotopes, compared to the results of computer simulations. The isotope that was under analysis in this work was Nickel-60 - which has 28 protons and 32 neutrons - this is because it is the daughter-isotope of the original isotope, Iron-60. 90 per cent of the

Clues from meteorites

How these space rocks are essential in understanding the origin of Solar System



Floating through space
When a meteorite is travelling through space, it is referred to as a meteoroid. They are the oldest, and most well preserved, bodies in the Solar System.

Entering the Earth's atmosphere
When a meteoroid enters the Earth's atmosphere, it is then a meteor. If a meteor is large enough, it can survive the intense friction of Earth's atmosphere.

iron in the universe is Iron-56, which has 26 protons and 30 neutrons. Because Iron-60 has four extra neutrons it is unstable, and the eventual victim of radioactive decay.

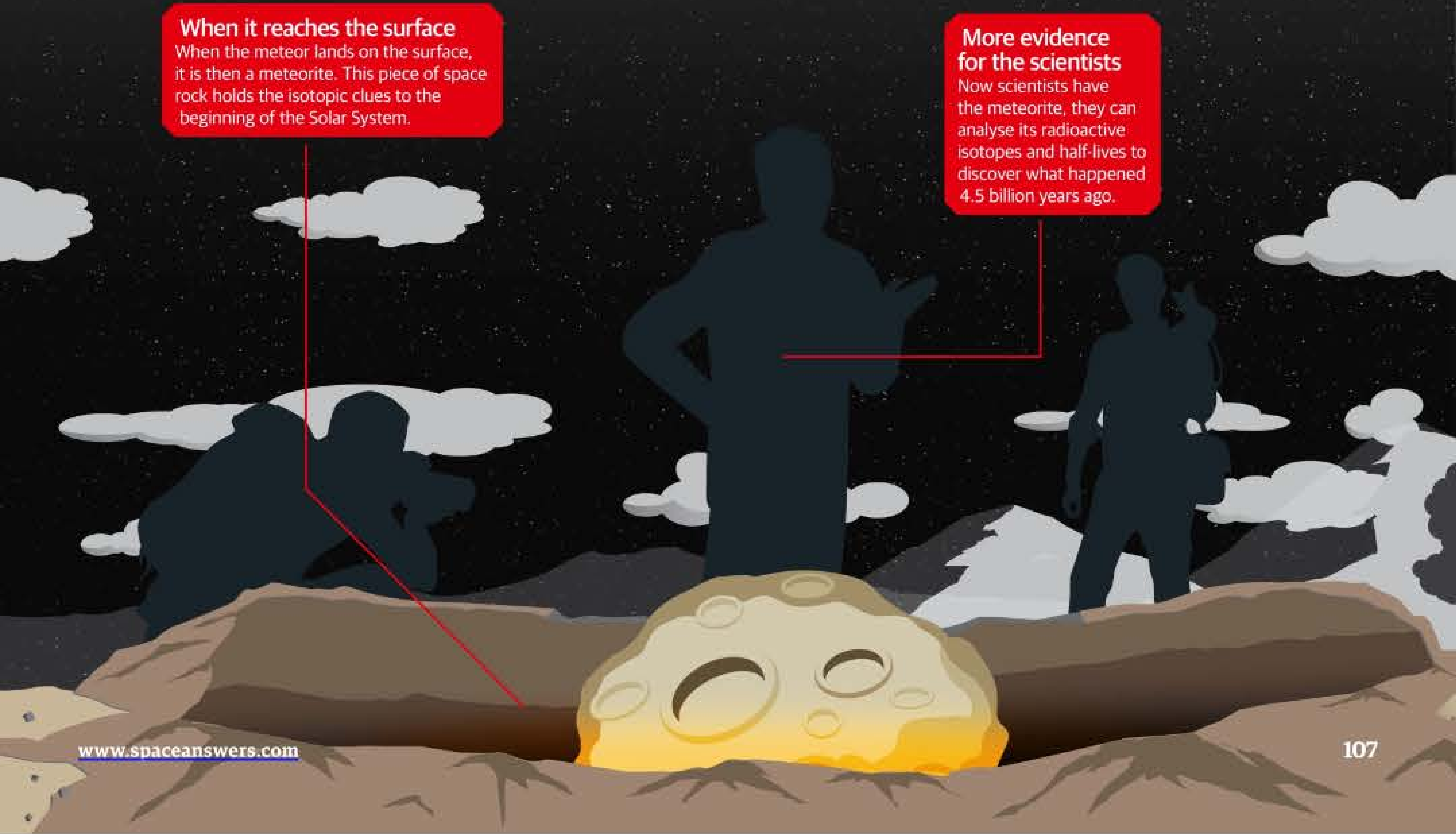
It is known throughout the universe that Iron-60 is produced in certain kinds of stars, including 'Asymptotic Giant Branch' (AGB) stars, which turn supernova later in their life. The half-life for Iron-60 is roughly 2.6 million years, which compared to the age of the Solar System is only a fraction of time. With this relatively short half-life, it is clear that all the Iron-60 has vanished from meteorites, which is why astronomers rely upon examining Nickel-60.

Dr Myriam Telus, also of Carnegie Institute of Science, analysed the isotope Nickel-60 within meteorites. Her studies confirm that the amount of Iron-60 present in the early Solar System is consistent with a supernova origin. By combining Telus' meteorite analysis with 3D hydrodynamical

Meteorite recovery is a very careful procedure, as scientists need to avoid contamination

© NASA/JPL-Caltech; NASA/H. Raab

Our planets, moons and asteroids all formed from the same protoplanetary disc



When it reaches the surface
When the meteor lands on the surface, it is then a meteorite. This piece of space rock holds the isotopic clues to the beginning of the Solar System.

More evidence for the scientists
Now scientists have the meteorite, they can analyse its radioactive isotopes and half-lives to discover what happened 4.5 billion years ago.

> "My work has focused on determining what type of shock wave can strike a dense molecular cloud core and cause it to collapse" **Dr Alan Boss**

Wolf-Rayet stars are extremely massive and exhibit a drastic expulsion of stellar winds and shock waves towards the end of their life

calculations, Boss is confident that a supernova caused the collapse of our presolar cloud. "My work has focused on determining what type of shock wave can strike a dense molecular cloud core and cause it to collapse, while simultaneously injecting sufficient shock wave material to explain the meteoritical evidence," Boss tells **All About Space**. "Shock waves from massive Wolf-Rayet stars, from protostellar outflows and planetary nebula blown off by AGB stars all seem to fail to achieve both triggering and injection: so far only a supernova shock wave seems able to meet both criteria."

The work that Boss has conducted has allowed him to add some physical constraints to the pre-

© NASA/JPL-Caltech; Hubble Legacy Archive/NASA/ESA/Judy Schmidt

The Orion Nebula (seen here in infrared) is a gaseous cloud home to star formation

supernova star. Based on the isotopes produced, and ultimately integrated in our Solar System, the original star must have been between twenty and twenty-five solar masses. Not only that, but Boss has also estimated how far away this star must have been. "The supernova was probably about ten parsecs (33 light years) away from the presolar cloud. This distance is what is needed to slow down the supernova shock wave to a speed that can result in triggering and injection," he explains.

There has also been another study along the same lines by Professor Yong-Zhong Qian and his team at the University of Minnesota. Similar to Boss' study, Qian and his team produced computer models, and then compared them to results of meteorite analysis. Qian's study differed in that they focused on low-mass supernovae (stars with masses less than twelve-times the mass of our Sun), and they investigated different isotopes that would arise from the stellar explosion. The isotope in this study is on Beryllium-10 (which contains four protons and six neutrons), as it is commonly found in meteorites. It has caused a bit of a perplexing anomaly for astronomers, as they can't seem to explain its presence. It was originally thought that this isotope was formed via spallation, a process where high-energy particles strip away protons or neutrons to form a new nucleus, by cosmic rays. In response to this, Qian argues that this theory involves too many uncertain inputs, and also presumes that Beryllium-10 cannot be produced in supernovae.

Using new models of low- and high-mass supernovae, Qian and his team showed that Beryllium-10 can be created in both of these supernovae. However, it is only low-mass supernova that could explain the vast amounts of Beryllium-10 shown in meteorite records, and even a few other elements. "The findings in this paper have opened up a whole new direction in our research," Qian said. "In addition to explaining the abundance of Beryllium-10, this low-mass supernova model would also explain the short-lived nuclei Calcium-41, Palladium-107 and a few others found in meteorites. What it cannot explain must then be attributed to other sources that require detailed study."

Unfortunately there is still so much more to be studied to provide a definitive answer. We currently have an array of puzzle pieces, but only half the puzzle is solved. The next step for Qian and his team is to uncover the outstanding mysteries of the other short-lived nuclei present in the meteorites, which includes introducing the presence of Lithium-7 and Boron-7 into the theory. Boss also emphasised the need for more meteorite evidence, unfortunately it is extremely rare for a piece of space rock to survive the Earth's atmosphere and land for study.

Until a new piece of space rock breaks through the atmosphere and crashes on the ground successfully, astronomers just have to work with what they've got. It is clear though that there is enticing, promising and intelligent work going into the subject, and scientists are becoming ever closer to finding out the true answer of how our Solar System was created.

WHAT'S NEXT FOR HUBBLE?

The long-serving space telescope has been observing the universe for 28 years. What's next on its horizon could lead to even more groundbreaking discoveries

Written by Lee Cavendish

When the Hubble Space Telescope was launched on 24 April 1990, no one thought it would last as long as it has. NASA and the European Space Agency (ESA) had collaborated to create a groundbreaking, audacious space telescope, but it didn't rise to prominence without its hiccups. Initially scheduled to launch in October 1986, the tragic loss of Challenger in January 1986, forced the agencies to postpone Hubble's launch by four years.

When the launch date finally came around, the long-awaited Hubble Space Telescope flew on board the Space Shuttle Discovery (STS-31). Discovery positioned Hubble at an altitude of 569 kilometres (353 miles) over our heads. At last the telescope was ready, and astronomers couldn't wait to feast their eyes upon the wonders of the universe it could reveal. But, unfortunately, there was another setback.

Astronomers were hoping to view the most crisp, clear and incredible images of galaxies and nebulae. Instead, they were saddened by the return of blurry and out-of-focus images. An incorrectly installed null corrector led to a lens being out of focus by 1.3mm (0.051 inches), almost resulting in a $4.7 billion (approximately £3.4 billion) white elephant. However, with some creative thinking, corrective optics were installed on the first servicing mission in 1993, and astronomers could finally marvel at its majestic images and insightful data.

After four more servicing missions, the last in 2009, Hubble has been a picture of health. "Since the execution of Servicing Mission 4 in 2009, Hubble has been operating at its peak in terms of science productivity, and astronomers' interest remains at all-time highs now almost 28 years after its launch," explains Patrick Crouse, project manager of the Hubble Space Telescope, to **All About Space**.

The longevity of Hubble has been a pleasant surprise, with many scientists thinking Hubble would be long gone before the launch of its successor, NASA's James Webb Space Telescope (JWST), due to be launched in the spring of 2019. Now it looks more likely that the space telescopes' lifetimes will overlap, giving scientists and researchers a few years to utilise having two of the greatest telescopes in space at the same time to gather precious information about the universe.

There is something Hubble can do that the JWST cannot, and that's observing ultraviolet light. JWST will be able to observe visible to mid-infrared light in unprecedented detail, but not ultraviolet. This is why the Hubble scientists are urging researchers to gather as much ultraviolet information as they can using Hubble before it's too late. Once Hubble is decommissioned, these precise measurements of celestial objects in a wavelength unperceived by the human eye will no longer be available.

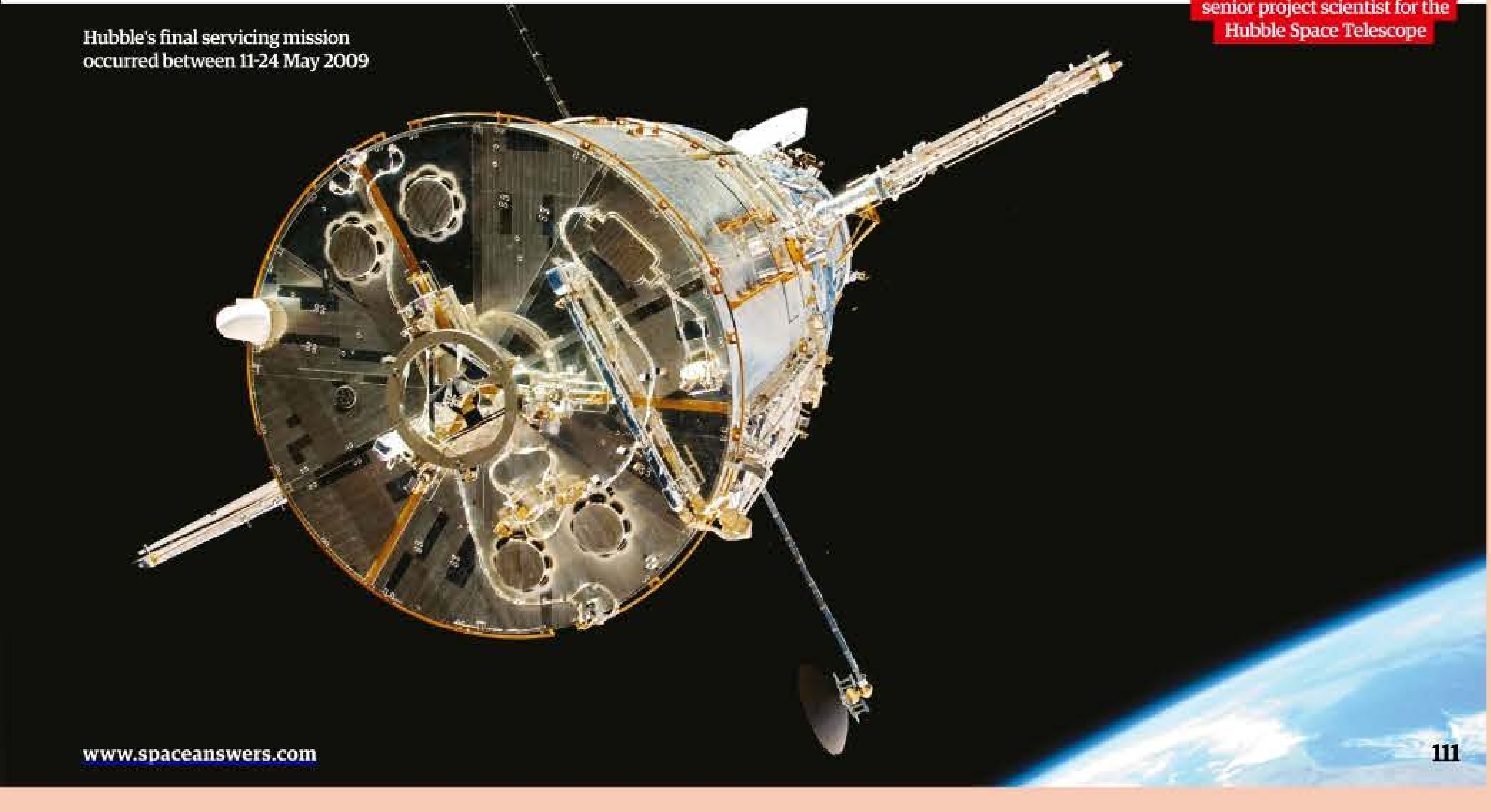
"We're encouraging them [researchers around the world] to consider making ultraviolet light observation proposals in order to give us information and data for future use. This will be more scientifically valuable because the Hubble Space Telescope can see in ultraviolet light, but there's no space telescope [planned to launch] in the near future that will be able to make these observations, and we cannot receive ultraviolet light from the ground because the atmosphere blocks it," Dr Jennifer Wiseman, senior project scientist for the Hubble Space Telescope, explains. "Hubble is unique in this capability of doing ultraviolet light observations and it is very informative for all kinds of astronomy. We use it both for studying the Solar System as well as studying the intergalactic medium - the material that connects galaxies. Those are just two examples of features in space that ultraviolet observations can truly illuminate and help us understand."

Ultraviolet light can tell us a lot of hidden information about the universe, particularly about the birth of hot, young stars. The intergalactic medium contains copious amounts of gas and dust, material fundamental for bringing life to stars in the universe. Ultraviolet spectroscopy - the splitting apart of light to observe chemical signatures - can tell us what elements are in these gas clouds, what temperature it is and even their density. From this, we can deduce what the ideal conditions are for stars to be born.

The Space Shuttle Discovery (STS-31) was launched from the Kennedy Space Center, Florida, United States on the 24 April 1990

> "Hubble is unique in this capability of doing ultraviolet light observations. It is very informative" **Dr Jennifer Wiseman**

Dr Jennifer Wiseman is the senior project scientist for the Hubble Space Telescope



Hubble's final servicing mission occurred between 11-24 May 2009

As making use of a telescope living on borrowed time is of the highest priority, Hubble scientists have introduced a 'mid-cycle proposal initiative'. "This is a special additional opportunity that astronomers have at two other times in the year, so we call them 'mid-cycle proposals', with a cycle being a year basically," says Wiseman. "These extra opportunities allow astronomers to make the case that if they go ahead and make a short observation with Hubble that's a time-sensitive issue, it will help them to have a richer proposal when the regular annual cycle proposal comes around."

By allowing astronomers to fast track the usual annual proposal process, assuming that their mid-cycle proposal fits the urgent protocol, the efficiency for the 28-year-old space telescope can be optimised while it is still in fantastic condition. Even if this work never goes further than that, the observations will always remain in the fine collection of datasets that is the Hubble archives. Already the Hubble archive is making tremendous contributions to science with new discoveries; about half of the published scientific papers based on Hubble data have come from this trove of forgotten gems.

Patrick Crouse has been Hubble's project Manager for eight years

"There is another area we are using Hubble in which I think is of prime importance, and that is studying our Solar System," explains Wiseman. Although Hubble spends a lot of time staring into deep space, pondering upon the darkest, deepest galaxies in the universe, it can also tell us much about the outer planets in our Solar System. The only instruments that can produce clearer pictures are the ones that have flown past the planets, such as Juno, Cassini, the Voyager spacecrafts and so on. The advantage that Hubble has over these exploration spacecrafts, however, is that Hubble can observe these planets periodically for many years.

With this perpetual 'checking in' on our outer planets, Hubble managed to capture the spectacular collision between comet Shoemaker-Levy 9 and Jupiter in July 1994. Hubble has also deduced that the aforementioned planet's Great Red Spot (GRS), a storm about 1.3-times the diameter of Earth, is shrinking. Even today scientists continue to make new discoveries thanks to these periodic observations. For instance, scientists recently caught a storm - originally long enough to stretch from the East Coast of the United States to Portugal - on the face of Neptune shrinking before its very lens.

As for the future, scientists are extremely keen to keep a close eye on Jupiter's moon, Europa. Europa has exhibited plumes of water escaping from within the moon, meaning that there could be a subsurface ocean. With Hubble's ultraviolet capabilities a lot can be learned from the water beneath the ice, and it could even point out the existence of microbial life.

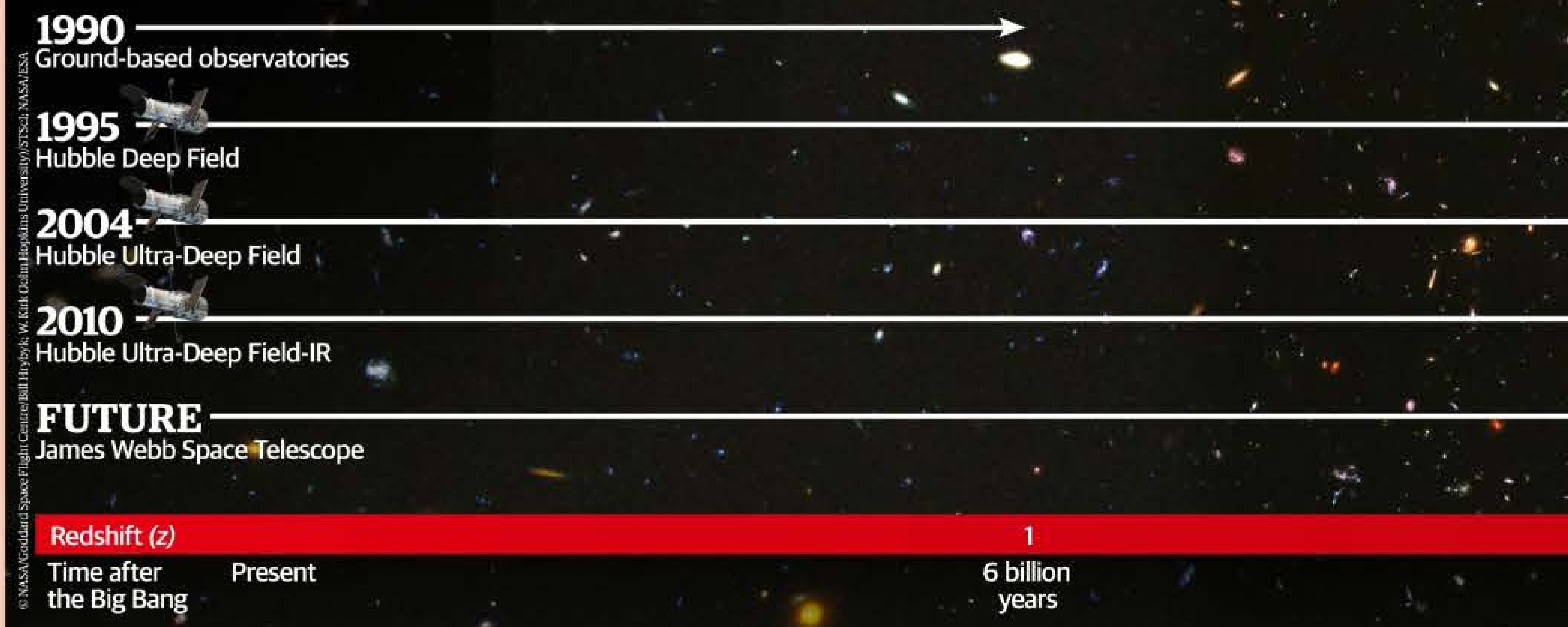
Even beyond our Solar System we are still learning about planets in our galaxy, the Milky Way. More specifically the atmospheres of exoplanets - planets orbiting a star other than our Sun. "Hubble is very useful for studying the atmospheric compositions of some of these exoplanets, so we're using Hubble very intensively to do that on as many exoplanets as we can," explains Wiseman. "We've already found water vapour in the atmospheres of several exoplanets, and we're continuing to characterise as many as we can in several wavelengths of light."

Moving beyond the Milky Way, the Hubble Space Telescope has played a vital role in understanding the expansion of the universe or, more appropriately, causing even more confusion surrounding the expansion of the universe. Dr Adam Riess, 2011 Nobel Prize laureate and astrophysicist at the Space Telescope Science Institute and Johns Hopkins University, both in Baltimore, Maryland, United States, formulated an innovative technique that led to a more accurate figure for the Hubble constant.

The Hubble constant is the rate at which the universe is expanding, and after eight long years of observing Cepheid stars, Riess and his team were able to conclude that the universe is expanding five to nine per cent faster than expected. When the refined Hubble data is compared with information we can see from the cosmic microwave background

How Hubble will benefit the James Webb Space Telescope

When NASA's James Webb Space Telescope receives first light it will be ready to peer earlier into the universe's history than ever before. Until then, Hubble can identify and analyse the earliest galaxies its optics allow, singling out targets for the JWST to look at once its time has come.



© NASA/Goddard Space Flight Centre/Bill Hrybyk; W. Kirk (John Hopkins University)/STScI; NASA/ESA

(ancient radiation left from the Big Bang), astronomers can't get the two results to match up, which means there could be something wrong with our understanding. Riess says that this can be thought of as building a bridge, with the Hubble findings on one side and the cosmic microwave background data on the other. "You start at two ends, and you expect to meet in the middle if all of your drawings are right and your measurements are right. But now the ends are not quite meeting in the middle, and we want to know why."

This incentive continues to drive astronomers in their quest to understand the elusive dark energy theorised to be fuelling the expansion of our universe. Since 2005, the uncertainty for the Hubble constant value has been reduced to just 2.4 per cent, which is a 76 per cent reduction. However, Riess and his team strive to make this uncertainty just one per cent, and hopefully connect the bridge between the two sets of data.

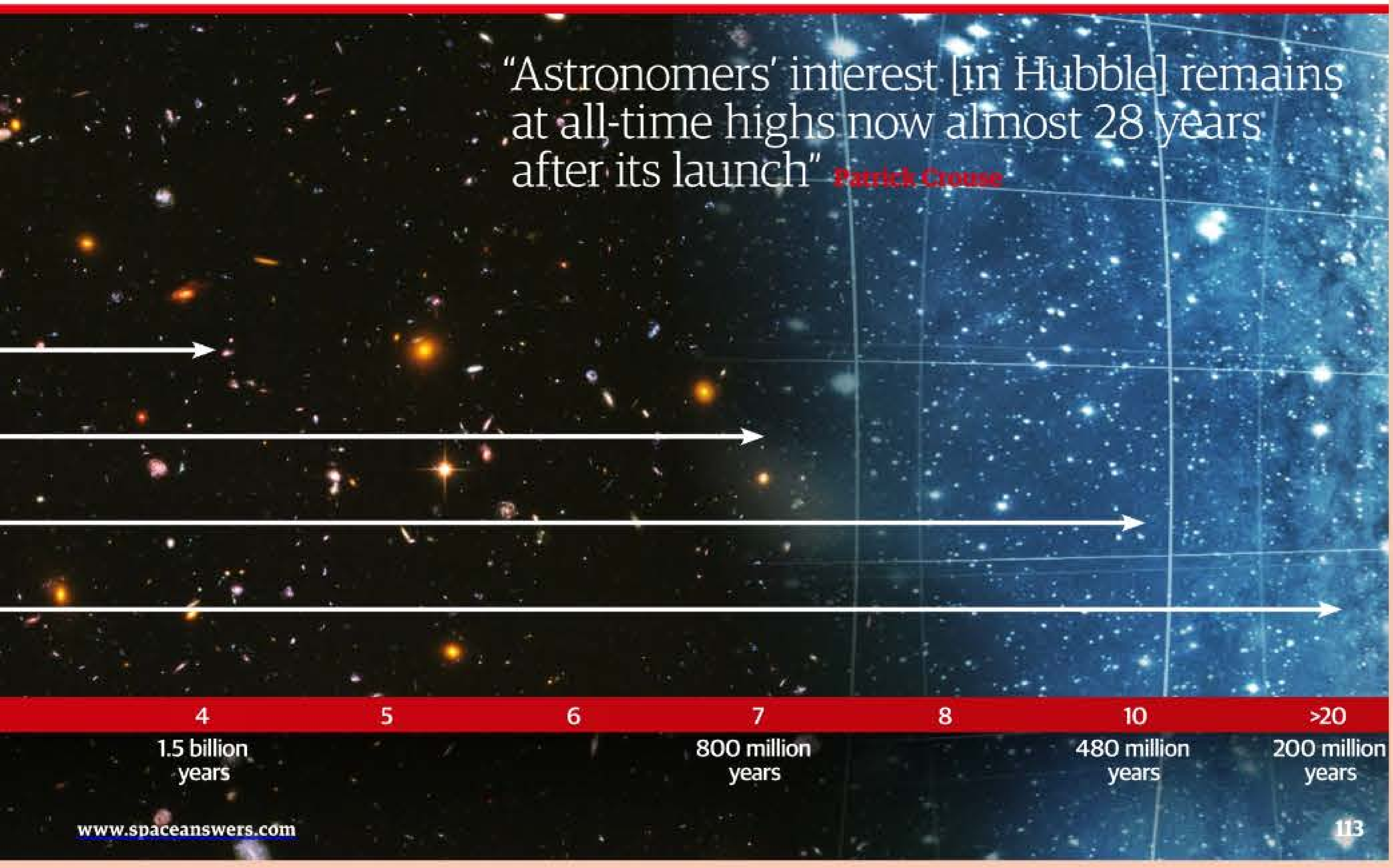
In spite of all that, it has become abundantly clear that the hard-working Hubble team at NASA are planning heavily for the arrival of the agency's highly anticipated James Webb Space Telescope. Prior to its arrival, Hubble will spend a fair amount of its time in the coming years undergoing preparatory observations and getting all the aims, objectives and targets ready for when the new space telescope receives first light.

"We look forward to overlapping operations with the JWST telescope and the resulting

Adam Riess won the Nobel Prize in Physics in 2011 for his research on the expansion of the universe

On Hubble's 25th anniversary, it celebrated by snapping this marvellous shot of the star cluster Westerlund 2

"Astronomers' interest [in Hubble] remains at all-time highs now almost 28 years after its launch" **Patrick Crouse**



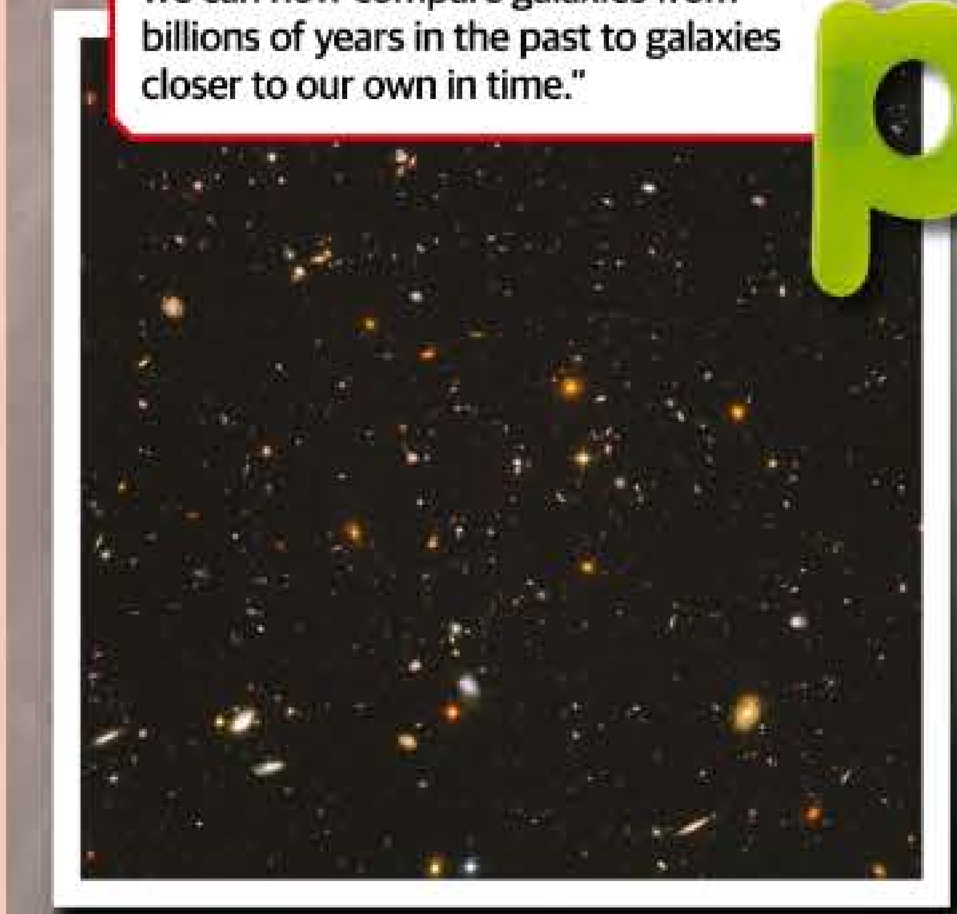
The Hubble team pick their favourites

The scientists behind the mission reveal some of their favourite images and explain what they mean for understanding of the universe

Hubble's Ultra-Deep Field

Dr Jennifer Wiseman, senior project scientist

"The image is mind-blowing when you realise that this tiny area of the sky contains thousands of galaxies. These galaxies showed up when Hubble collected light over several days, revealing even very faint objects. What is incredible to me is that astronomers have analysed many of these galaxies and determined their distances so that we can now compare galaxies from billions of years in the past to galaxies closer to our own in time."



M104, Sombrero Galaxy

Kevin Hartnett, science operations manager

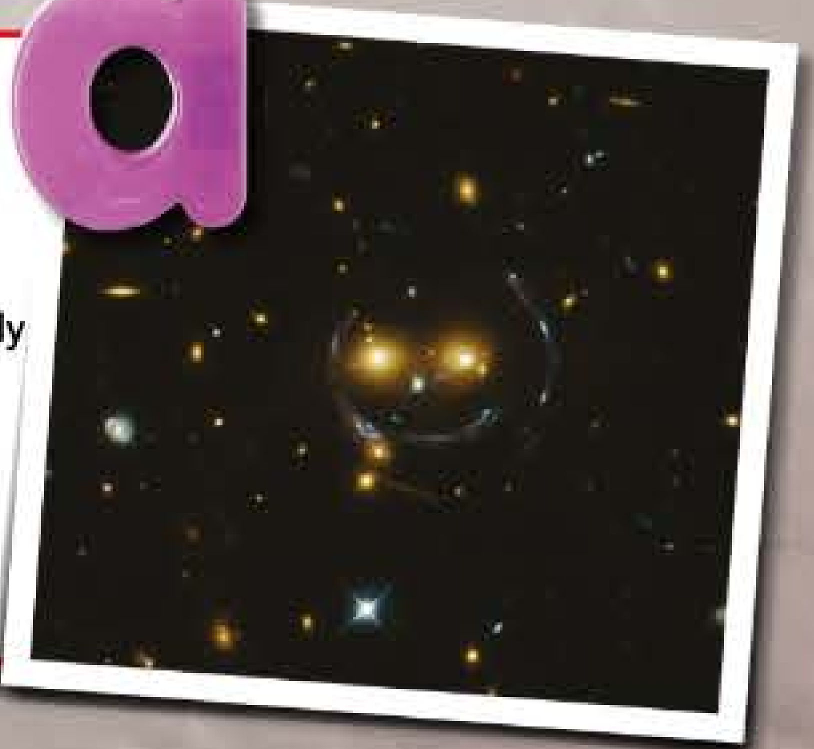
"I chose this one because of its majestic expanse, exquisite details along its dusty disc, glowing stellar halo, numerous globular clusters, and the tiny background galaxies visible in the image. I've seen M104 with my own backyard telescope, so this makes it all the more interesting."

Galaxy cluster SDSS J1038+4849

Dr Knicole Colón, deputy operations project scientist

"What I like about this image is that it simply makes me happy when I look at it. When you see someone smile at you you're more than likely going to give a smile in return.

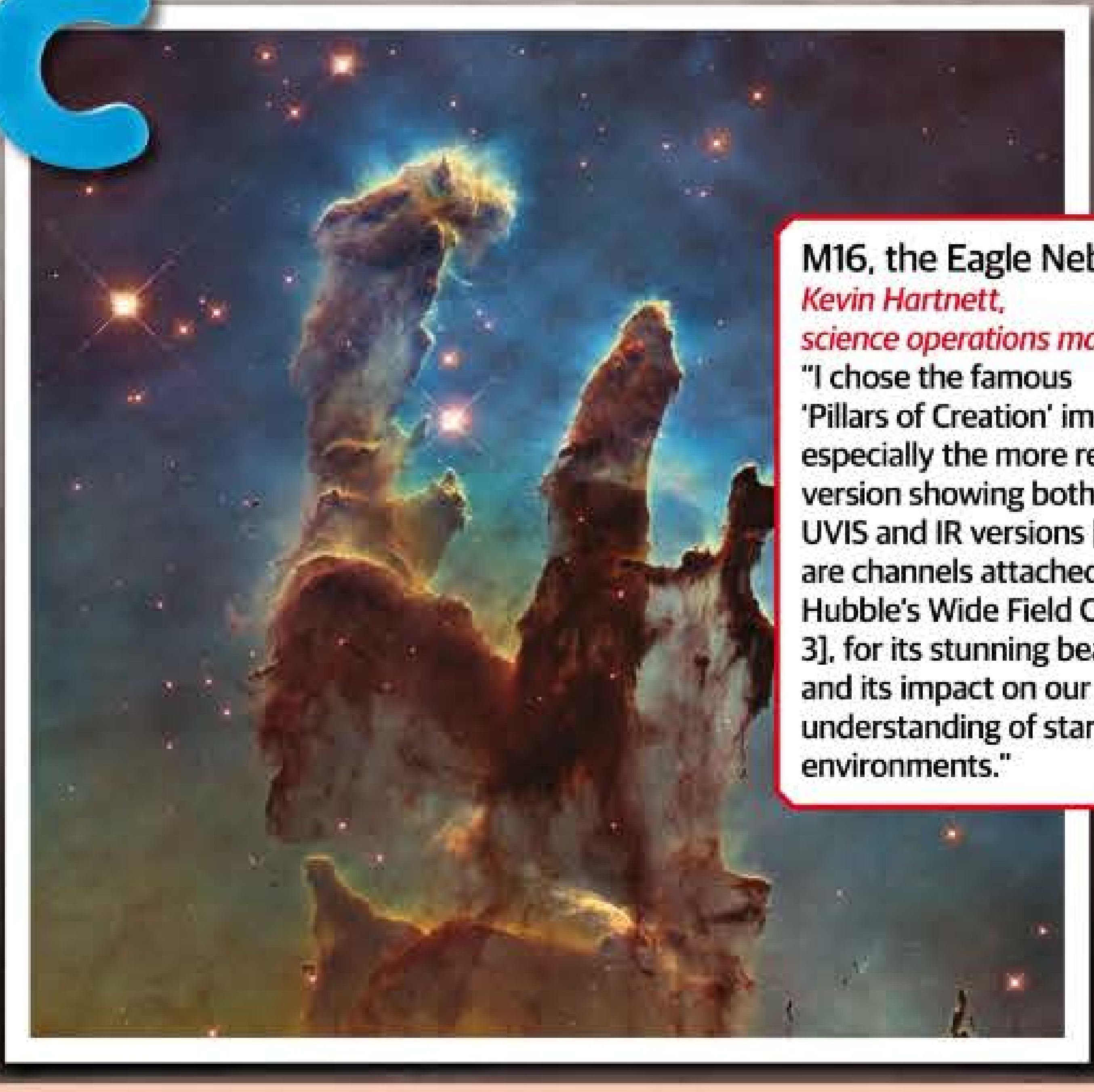
"To me, this is nature's way of showing us the beauty in the universe in a way that we as humans can relate. What this image shows scientifically speaking is a cluster of galaxies and the effects of gravitational lensing."



Fomalhaut System

Dr Knicole Colón, deputy operations project scientist

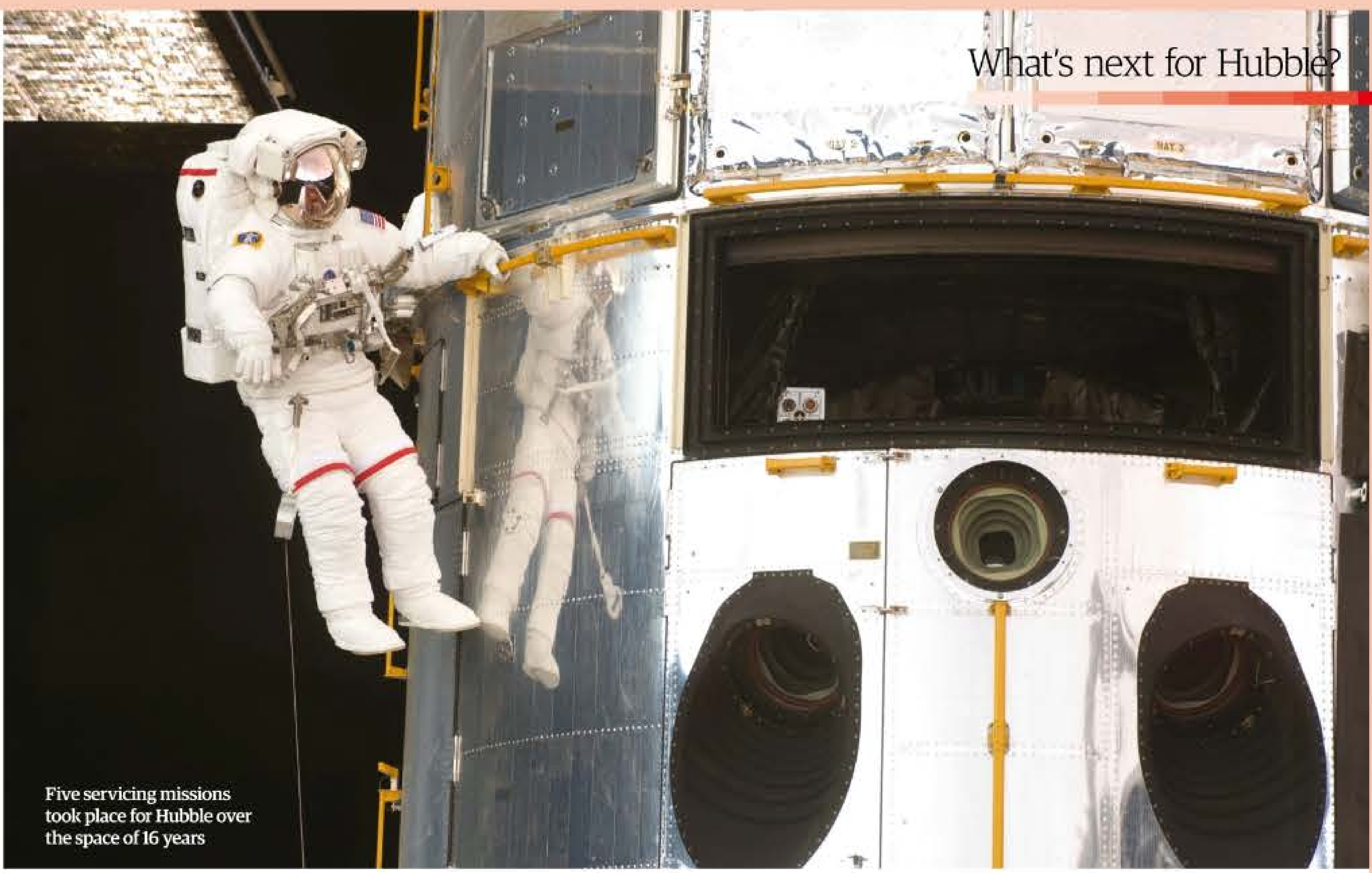
"The first time I saw this image my jaw might have literally dropped. I thought it was both beautiful and inspirational that we now live in a time when we can take 'direct' pictures of planetary-size objects orbiting other stars located tens of light years from our Solar System. Scientifically speaking, this image provides clues to how planets form within disks around stars."



M16, the Eagle Nebula

Kevin Hartnett, science operations manager

"I chose the famous 'Pillars of Creation' images, especially the more recent version showing both the UVIS and IR versions [both are channels attached to Hubble's Wide Field Camera 3], for its stunning beauty and its impact on our understanding of star-birth environments."



Five servicing missions took place for Hubble over the space of 16 years

"We look forward to similar, joint programmes with JWST so that investigators can coordinate the study of celestial objects in detail" **Kevin Hartnett**

complementary science opportunities, which we expect to be very exciting," says Crouse.

Kevin Hartnett, science operations manager of the Hubble Space Telescope tells **All About Space**: "Once James Webb Space Telescope is launched and is taking science we look forward to similar, joint programmes with JWST so that investigators can coordinate the study of celestial objects in detail panchromatically, that is, across the electromagnetic spectrum, from ultraviolet to infrared wavelengths."

The JWST will be able to do the same things as Hubble Space Telescope - minus ultraviolet observations - but better. With its 18 hexagonal mirrors, each beryllium blank is coated in gold, congregating into a 6.5-metre (21-foot) primary mirror, it will tower over Hubble's 2.4-metre (7.9-foot) mirror, allowing for marvellous light-capturing capabilities. With this incredibly powerful instrument at NASA's disposal, astronomers are now planning what the first targets will be in order to kick-start a new era of deep-space exploration.

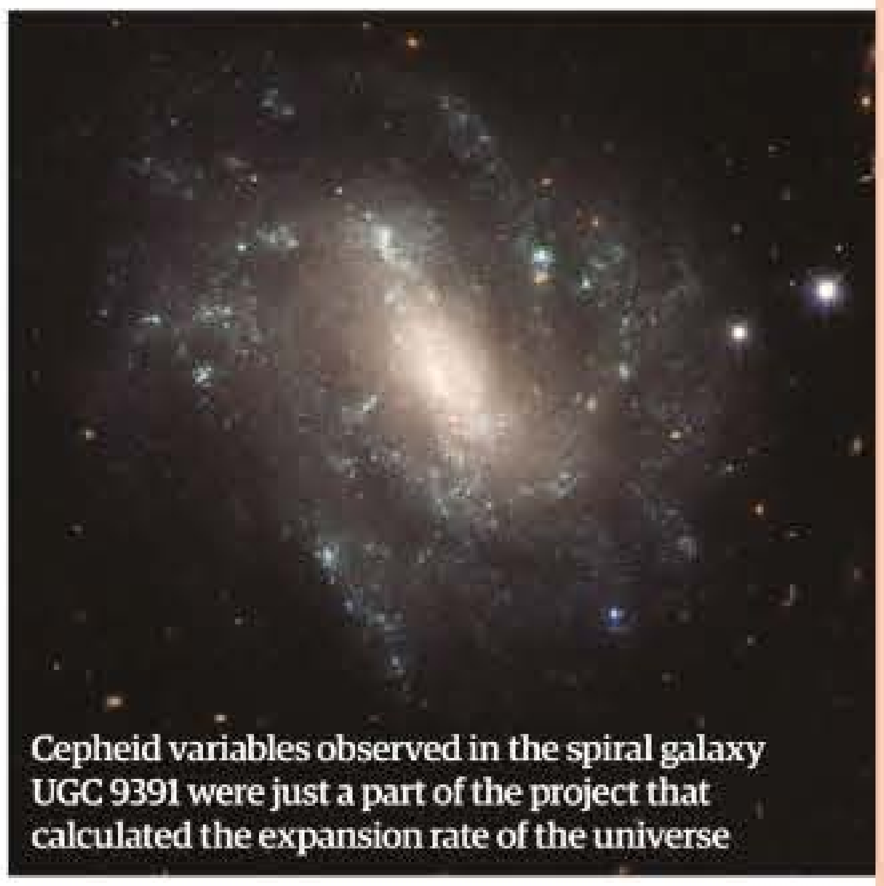
One area that astronomers around the world are at the edge of their seats for, in terms of JWST's preliminary results, are observations with respect to the most distant galaxies in the universe. The most distant galaxies are normally referred to as high-redshift galaxies. This is because the more distant the light source is, the more stretched the light's wavelength is towards the red part of the spectrum.

But what can these distant galaxies tell us about our universe? The answer is that they can tell us about the early ages of the universe, due to the limited speed of light and the large distance travelled since the birth of these galaxies.

In March 2016, Hubble imaged the most distant galaxy in the universe. It was dubbed GN-z11, based on the fact it has a redshift value (z) of 11. As light is limited to the speed of 300,000,000 metres per second (671,000,000 miles per hour), the light from GN-z11 had taken over 13 billion years to reach us. Hubble had just spotted a galaxy that formed just 400 million years after the Big Bang! With the greater light-gathering capabilities of JWST, we could potentially unlock a whole new horde of remote, young galaxies. This information can then tell us what the universe was like just a few hundreds of millions of years after the Big Bang.

Even after 28 years of around-the-clock operation, Hubble remains the most successful and scientifically significant telescope ever created. It is remarkable what it has done, what it is currently doing and what it will do in the future. However, with its longevity in question and the eventual arrival of the JWST, it's clearly important to utilise these precious final years. After all, Hubble has built, and will continue to build, an amazing collection of data for scientists all over the world to prosper from long after the telescope itself has gone.

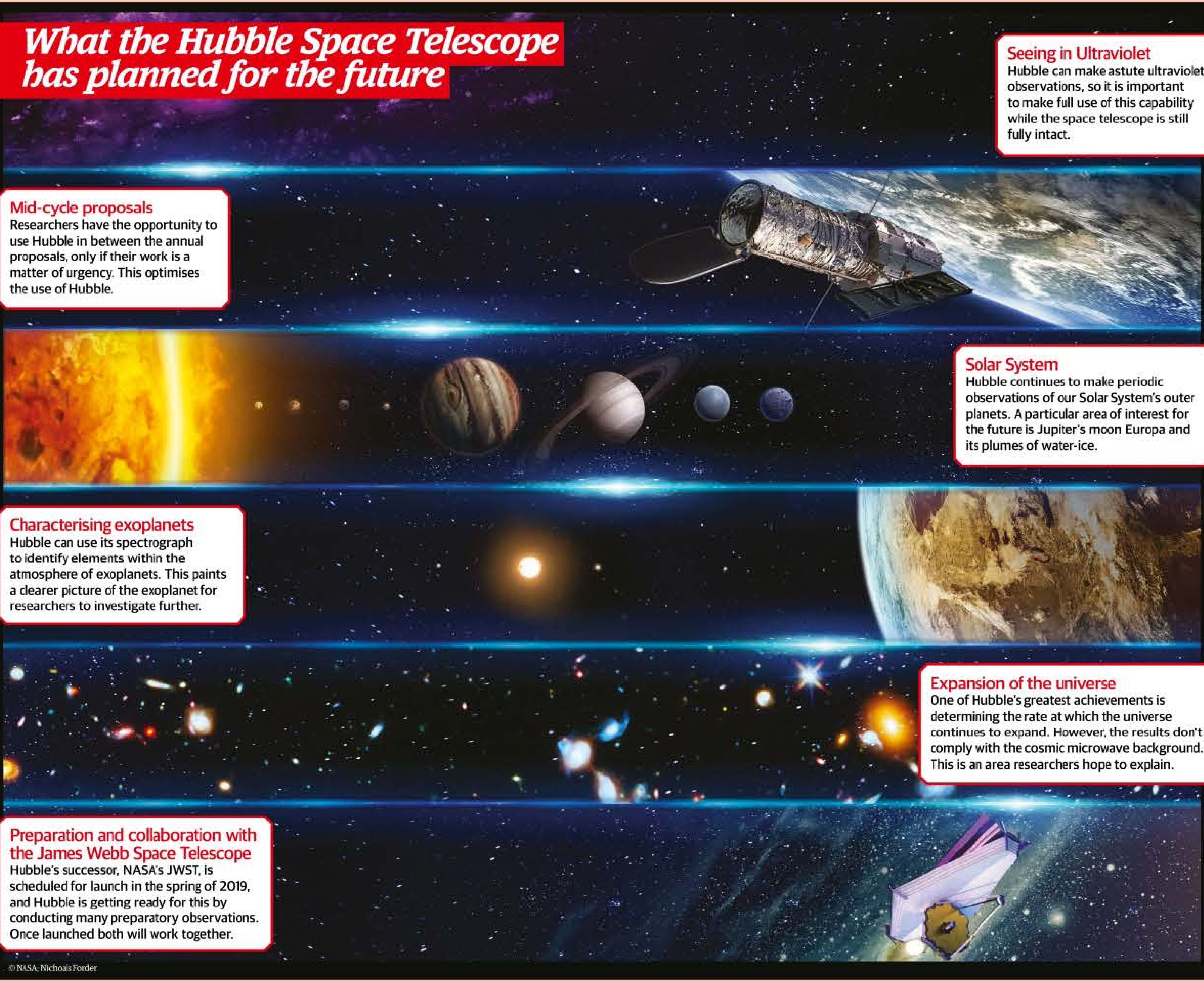
Hubble's unique ultraviolet capabilities emphasise the intense star formation occurring in a galaxy



Cepheid variables observed in the spiral galaxy UGC 9391 were just a part of the project that calculated the expansion rate of the universe

©ESA/NASA/Hubble

What the Hubble Space Telescope has planned for the future



Seeing in Ultraviolet

Hubble can make astute ultraviolet observations, so it is important to make full use of this capability while the space telescope is still fully intact.

Mid-cycle proposals

Researchers have the opportunity to use Hubble in between the annual proposals, only if their work is a matter of urgency. This optimises the use of Hubble.

Solar System

Hubble continues to make periodic observations of our Solar System's outer planets. A particular area of interest for the future is Jupiter's moon Europa and its plumes of water-ice.

Characterising exoplanets

Hubble can use its spectrograph to identify elements within the atmosphere of exoplanets. This paints a clearer picture of the exoplanet for researchers to investigate further.

Expansion of the universe

One of Hubble's greatest achievements is determining the rate at which the universe continues to expand. However, the results don't comply with the cosmic microwave background. This is an area researchers hope to explain.

Preparation and collaboration with the James Webb Space Telescope

Hubble's successor, NASA's JWST, is scheduled for launch in the spring of 2019, and Hubble is getting ready for this by conducting many preparatory observations. Once launched both will work together.

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Earth-orbit gives us the perfect vantage point for taking steps to save the planet

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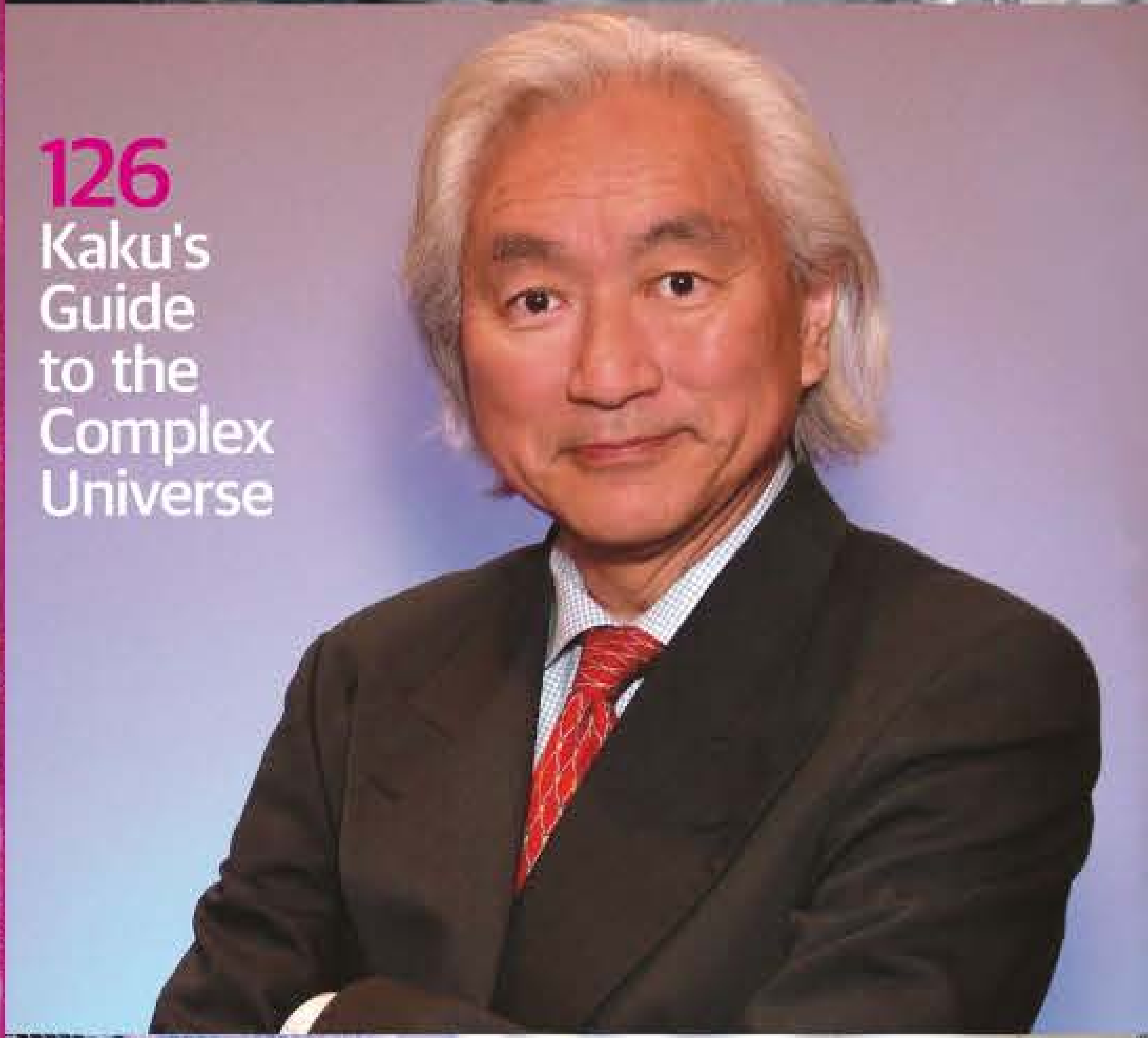

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HOW WE'RE BEATING CLIMATE CHANGE... *FROM SPACE*

Earth-orbit gives us the perfect vantage point for taking steps to save the planet

Reported by Libby Plummer

Climate change is one of the greatest challenges facing our planet today. Comprising a broad range of global phenomena – the primary cause being the burning of fossil fuels – it includes global warming, sea level rises, ice mass loss, and extreme weather.

While climate change skeptics inexplicably persist, some 97 per cent of scientists agree that climate-warming trends over the past century are most likely due to human activities, according to multiple studies published in peer-reviewed journals. Data unequivocally shows that global temperature has risen, oceans have warmed, ice sheets have shrunk, glaciers are retreating and sea levels are rising. Just this year, readings from NASA's Goddard Institute for Space Studies (GISS) in New York showed that February 2018 was the sixth-warmest February in 138 years.

So, how do we deal with such a problem? The response to climate change involves a two-pronged approach – mitigation and adaptation. The former involves reducing emissions and stabilising heat-trapping greenhouse gas levels in the atmosphere, and the latter focuses on adapting to climate change that is already happening or is expected to happen. This is where space comes in.

Space agencies around the world have a number of missions aimed at addressing climate change by gathering data from Earth observation missions. ESA's Climate Change Initiative (CCI) was launched in 2009 to meet the desperate need for climate data. "The aim of the CCI is to produce measurements of the Earth from space that have all been developed in a very similar way, using the same processes to look at satellite datasets over the land, oceans, ice, [and] the atmosphere," Andrew Shepherd, Professor of Earth Observation at the University of Leeds and science lead on the CCI ice sheet project, tells **All About Space**. "This is so anyone using any one of the datasets can be confident they've all been produced in the same way."

These standardised datasets are based on Essential Climate Variables (ECVs), which were developed by the Global Climate Observing System (GCOS). The ECV data is required to support the United Nations Framework Convention on Climate Change (UNFCCC) and the International Panel on Climate Change (IPCC). To date, the CCI has generated more than 100 datasets and 2.6 million files, comprising a massive 122 terabytes of data. The data is freely available online for climate researchers and policy makers to refer to.

A car hidden underwater for years is finally unearthed due to drought

Storms like Hurricane Irma could become more intense and destructive as a result of climate change

Much of the initiative's data is gathered by ESA's Copernicus programme, which is supported by a family of satellites called the Sentinels, as well as other non-ESA missions. Satellites have given us a new way of seeing the world and gathering information on inaccessible areas, making them a crucial element in the battle against climate change. As they remain in place for long periods of time, they can also show long-term global environmental changes on Earth that we might not necessarily be able to monitor from the ground.

Built specifically for the Copernicus programme, the Sentinel satellites carry instruments that can perform a range of tasks, including radar imaging and sea surface topography measurements. The Sentinel-5P, which is dedicated to monitoring air pollution, was the latest in the group to launch, blasting off from the Plesetsk cosmodrome on 13 October 2017. The Sentinel-3B is the next in line to be sent into orbit with a scheduled launch of 25 April 2018, and its wide-ranging mission will include taking vital measurements of ocean- and land-surface temperature, as well as forest cover.

Unsurprisingly, NASA also has a space-based programme for tackling climate change, known as the Earth Observing System (EOS), which is led by the flagship satellite Terra, the Latin name for Earth. Launched on 18 December 1999, Terra packs five instruments that work concurrently to observe Earth's atmosphere, ocean, land, snow, ice and energy balance. What's more, the on-board MODIS (Moderate Resolution Imaging Spectroradiometer) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instruments provide critical information for assessing and managing natural disasters and other emergencies.

Somewhat alarmingly, Terra was the subject of two cyber attacks in 2008, experiencing interference for a total of 11 minutes, with Landsat 7 also being targeted. However, despite the worrying

"Aside from ensuring ongoing awareness, another major challenge for climate experts is funding"

Forest fires are becoming more problematic due to rising temperatures in heavily-wooded areas

© NASA; ESA; NOAA/CIRA; David McNew/Getty Images; Justin Sullivan/Getty Images; Ekaterina_Simonova

What's happening to Earth?

We can already see some of the measurable effects of climate change on the planet

97%

Scientific consensus

The percentage of climate experts that agree climate trends observed over the last century are likely a result of human activity.

286

GIGATONNES PER YEAR

Ice sheets

The Antarctica and Greenland ice sheets have been losing mass since 2002, with 127 and 286 Gigatonnes lost respectively per year since then.

2016

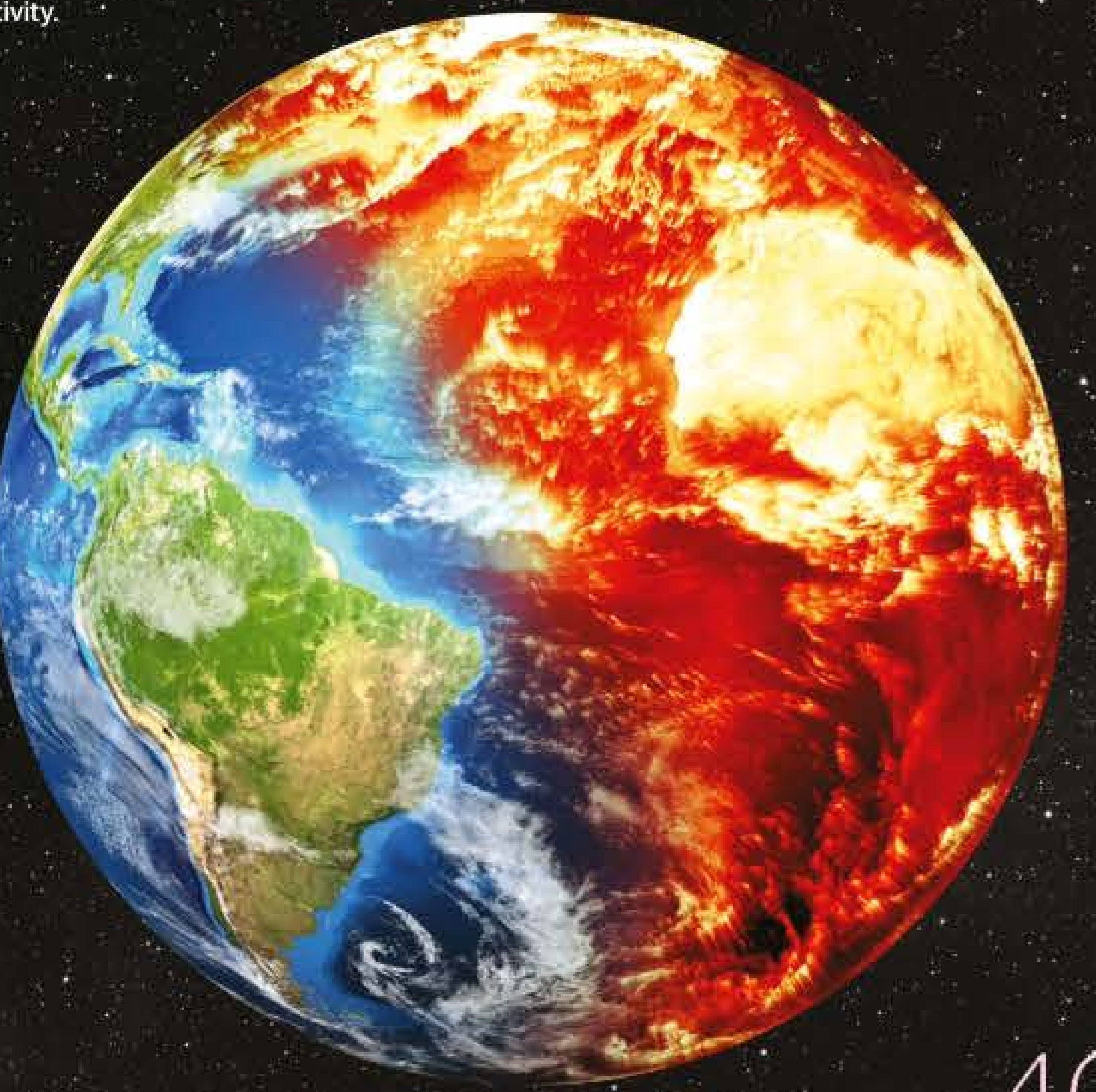
Global warming

2016 was the hottest year on record. 2017 was the second warmest and 2015 the third hottest.

30%

Biodiversity

Since Europeans started to colonise the Americas over 500 years ago, 30 per cent of biodiversity has been lost. This is expected to rise to 40 per cent unless steps are taken.



3.2mm

Sea level

Sea levels are currently rising at a rate of 3.2mm a year.

10%

Vegetation

Scientists estimate that around ten per cent of global carbon dioxide emissions come from deforestation.

250,000

Disease

Between 2030 and 2050, climate change is expected to cause 250,000 more deaths per year due to conditions like malaria and malnutrition.

1.0°C

Temperature

The world has warmed by about 1.0°C (1.8°F) since 1880. 17 of the 18 warmest years have occurred since 2001.

408ppm

PARTS PER MILLION

Pollution

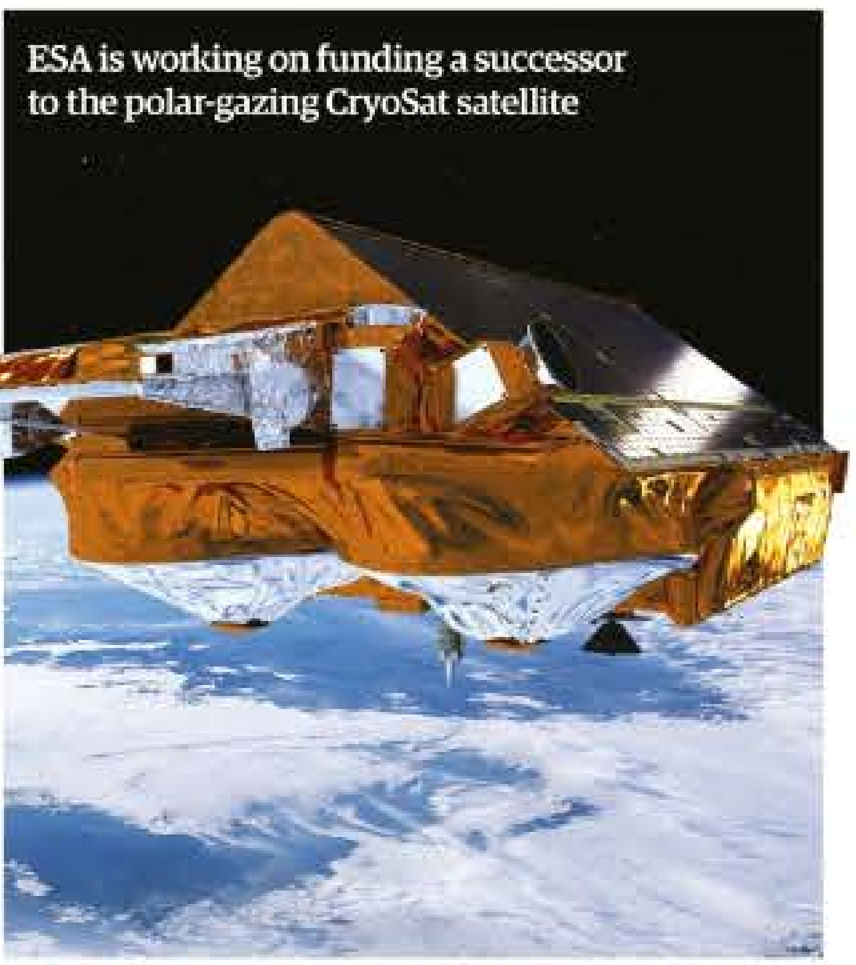
Atmospheric CO_2 levels measured at Mauna Loa Observatory, Hawaii, continue to increase, with the latest recording of 408ppm in February 2018.

hack, no commands were successfully sent to the satellites and no data was captured. The hack was suspected to be tied to the Chinese military, though China denied any involvement. Thankfully, no similar incidents have been reported since.

Also making up NASA's climate change-monitoring satellite roster is the Afternoon Constellation, or A-Train. This group of Earth-monitoring satellites fly in a coordinated orbit like a train on a track, only 705 kilometres (438 miles) above the Earth's surface. Until recently the constellation was made up of six satellites, including NASA's Aqua, Aura, and Orbiting Carbon Observatory-2, the NASA-CNES Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and Japanese space agency JAXA's Global Change Observation Mission - Water (GCOM-W1). Until February 2018, the cloud-monitoring CloudSat was also part of the formation until its orbit was deliberately lowered following the loss of one of its reaction wheels – the flywheel used for making small, precise manoeuvres. While the CloudSat will continue its science mission, it will no longer fly as part of the A-Train.

Many of NASA's additional Earth observation satellites were launched in collaboration with other organisations. The Landsat mission is a joint programme with the United States Geological Survey (USGS) and is the longest continuous space-based record of Earth's land in existence. The original Landsat 1 satellite launched in 1972, and the upcoming Landsat 9 is due to launch in 2020.

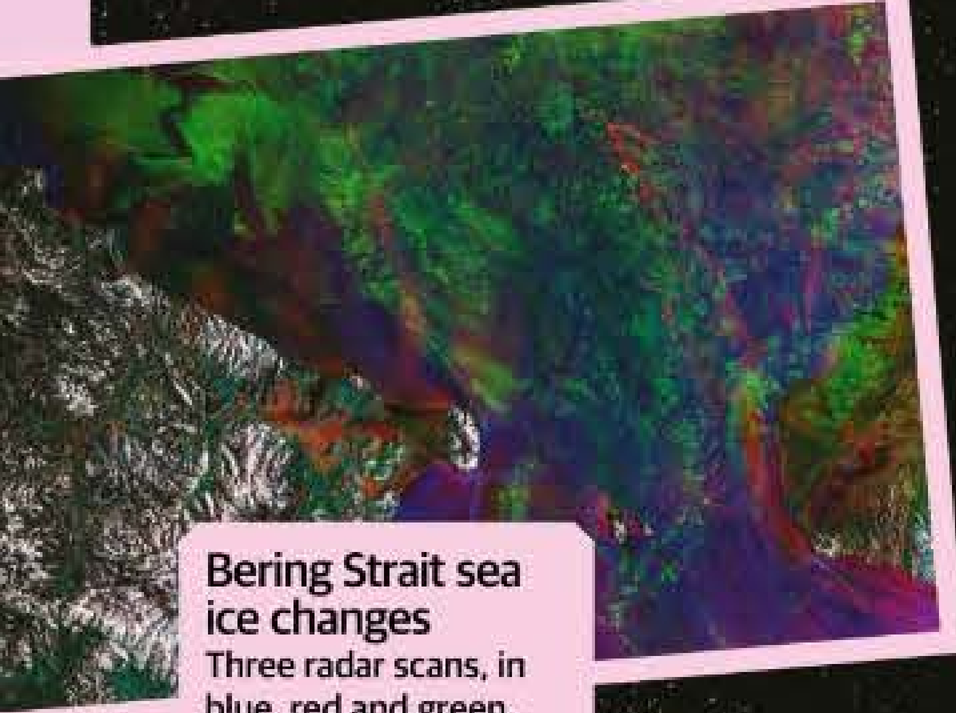
One of the latest instruments to join NASA's EOS operations in space was the Total and Spectral Solar Irradiance Sensor (TSIS-1), which became fully operational in March. This is designed to measure the total amount of sunlight that falls on Earth, and how that light is distributed among the infrared, visible and ultraviolet wavelengths. Rather than orbiting the Earth on a dedicated satellite,



ESA is working on funding a successor to the polar-gazing CryoSat satellite

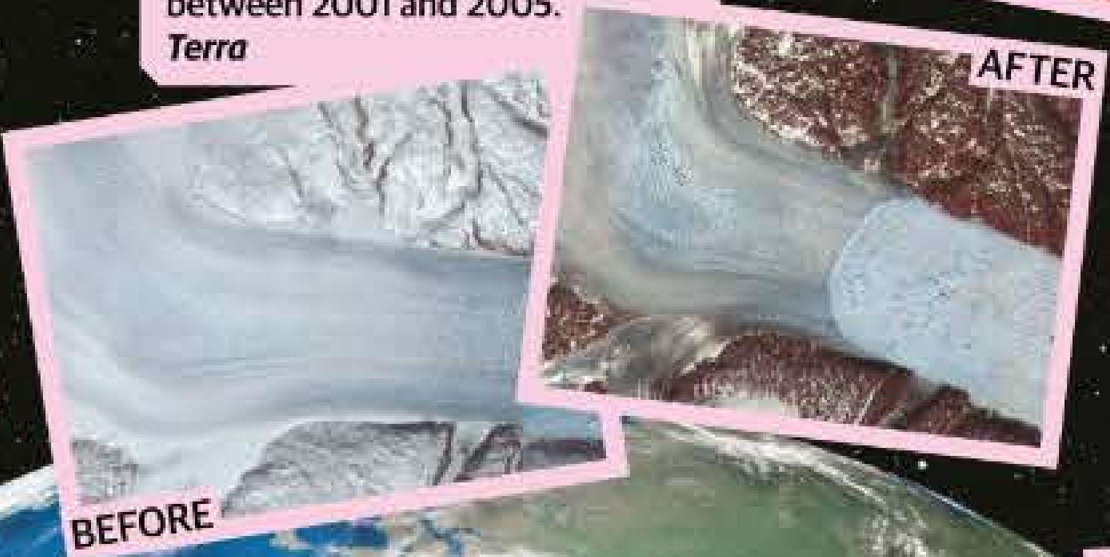
Evidence for climate change

Stunning images taken from space show the alarming impact on Earth



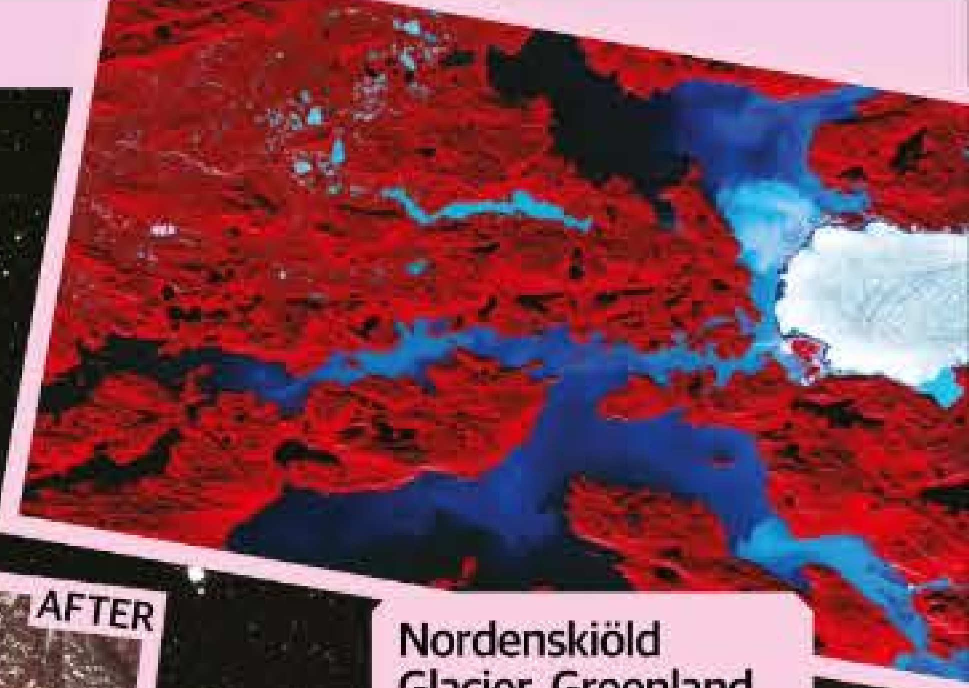
Bering Strait sea ice changes

Three radar scans, in blue, red and green, show how sea ice changed over four weeks in 2017 to 2018. ***Sentinel-1***



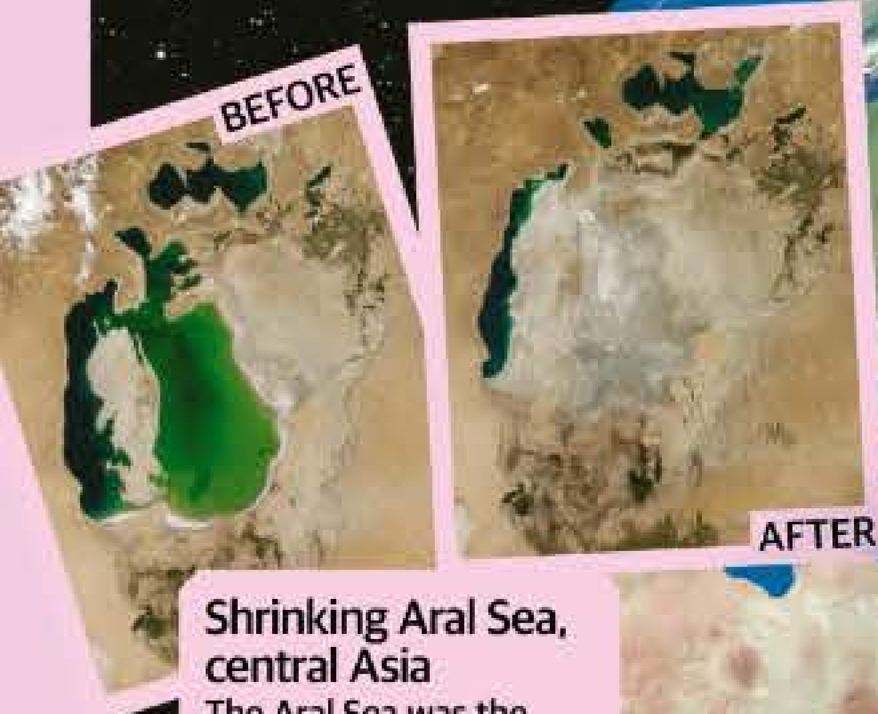
Helheim Glacier melt, Greenland

The Helheim Glacier is shown crumbling into icebergs, having retreated about 7.5 kilometres between 2001 and 2005. ***Terra***



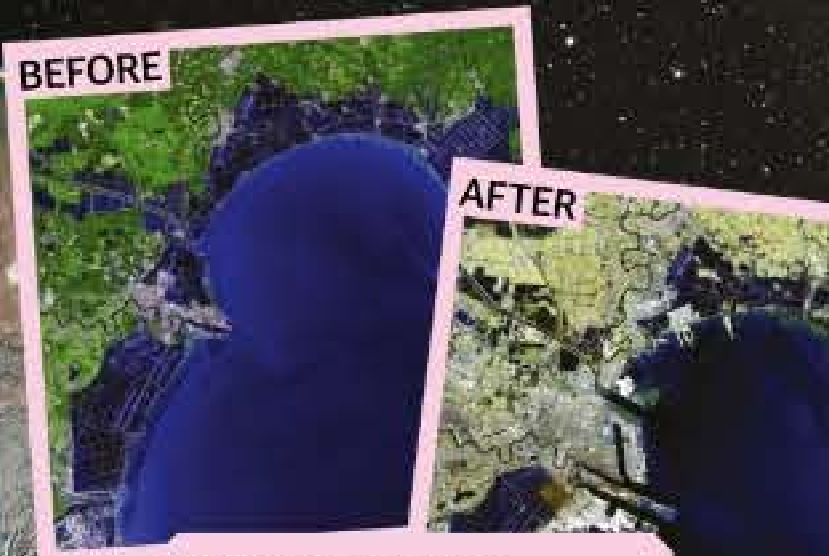
Nordenskiöld Glacier, Greenland

The Nordenskiöld Glacier (above) is just one of many glaciers draining Greenland's ice sheet. ***Sentinel-2A***



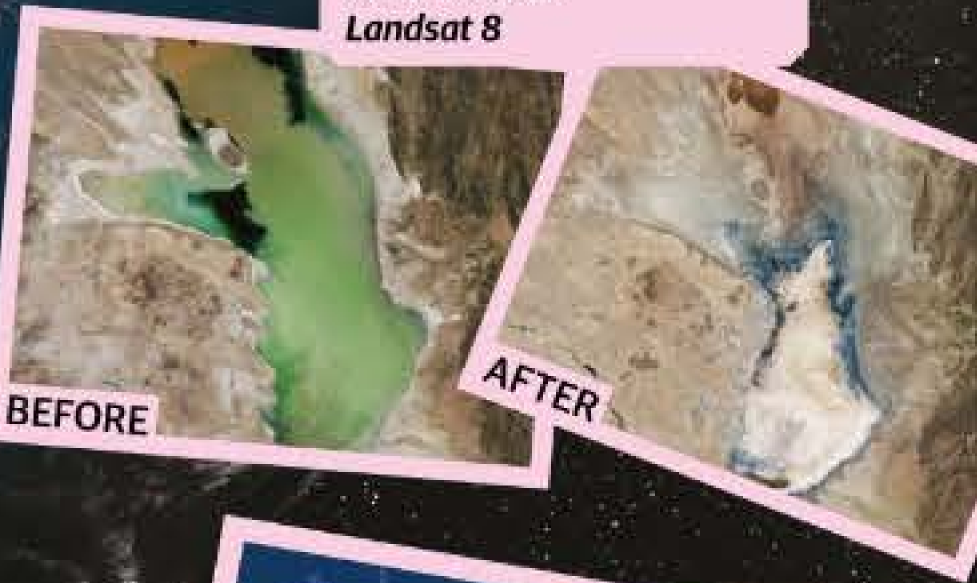
Shrinking Aral Sea, central Asia

The Aral Sea was the fourth-largest lake in the world until the 1960s, when the Soviets diverted water for crops. ***Terra***



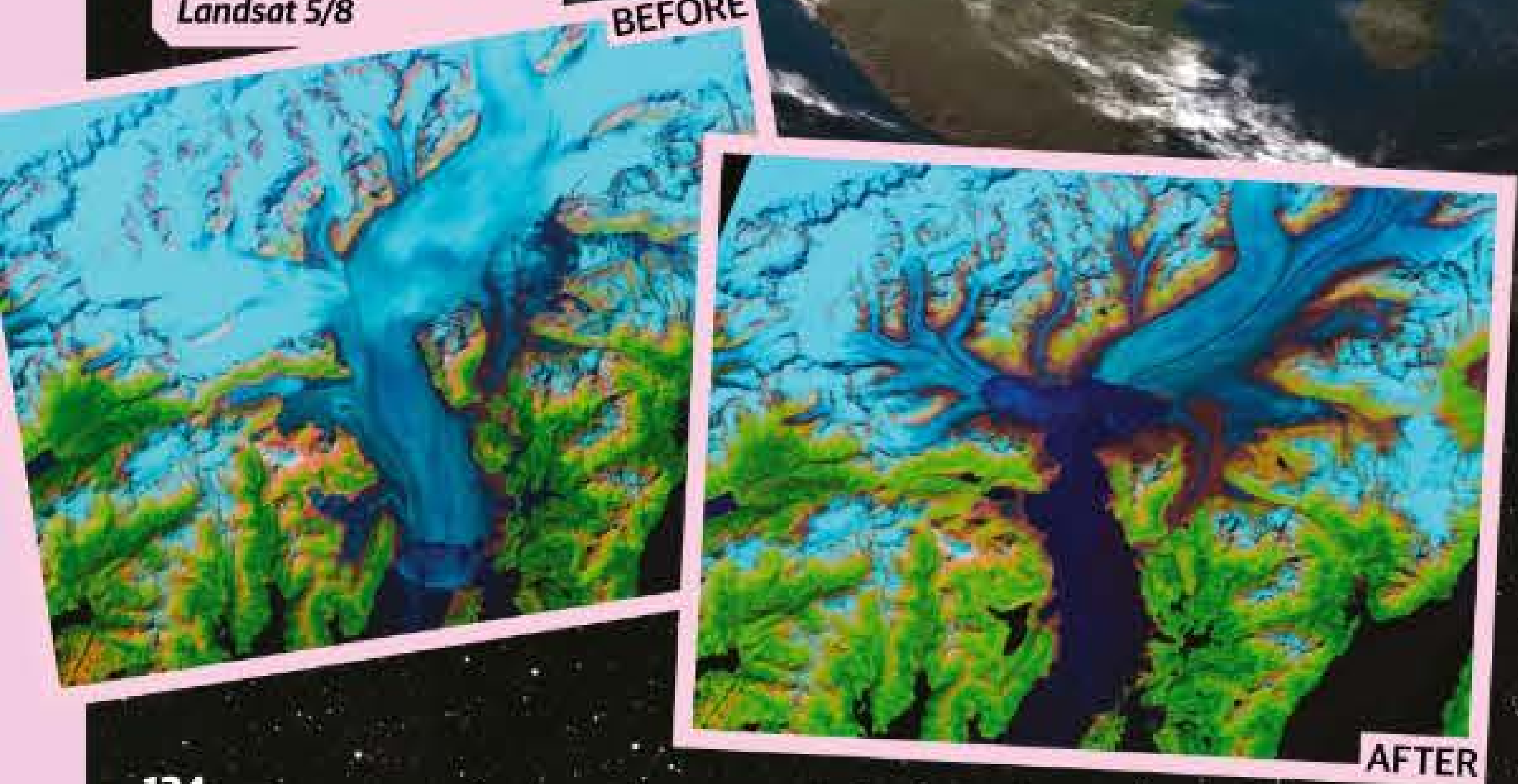
Binhai new area growth, China

Astounding urban sprawl can be seen on China's coast between 1992 and 2012. ***Landsat 7***



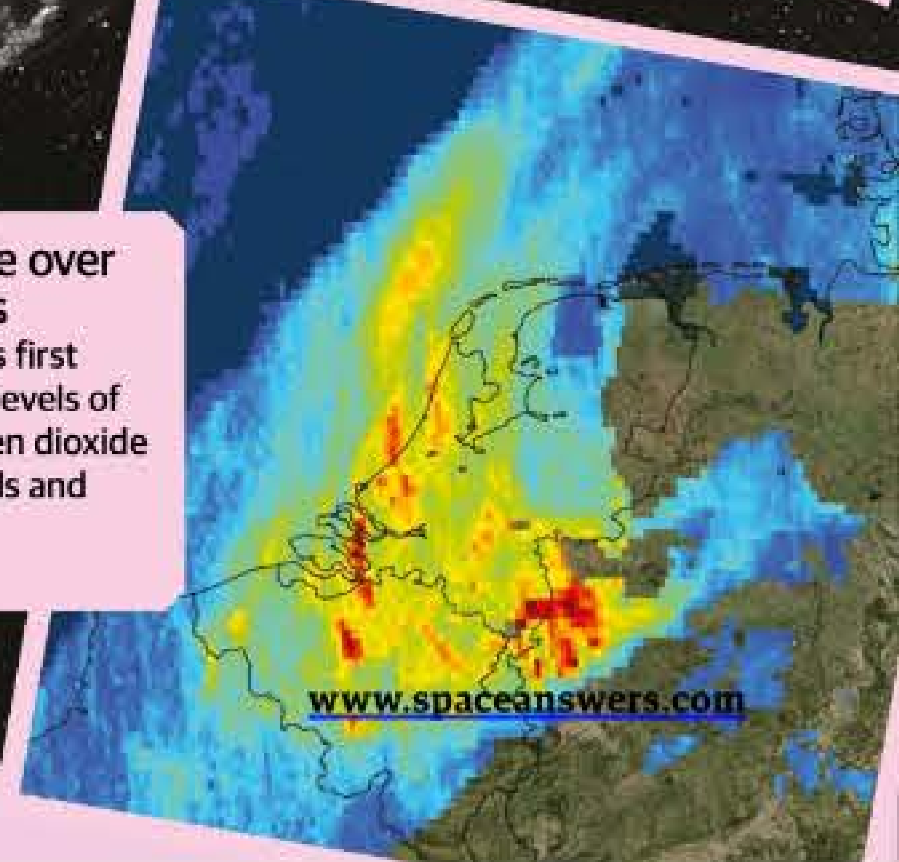
Drying Lake Poopó, Bolivia

Bolivia's second-largest lake dried up again in 2016 due to drought and diversion of water sources. ***Landsat 8***



Columbia Glacier melt, Alaska

The Columbia Glacier has been in rapid retreat since 1980 and has thinned significantly. ***Landsat 5/8***



Nitrogen dioxide over the Netherlands

One of Sentinel-5P's first images shows high levels of atmospheric nitrogen dioxide over the Netherlands and west Germany. ***Sentinel-5P***

The six Sentinel missions carry a range of instruments for gathering data for the Copernicus programme

the TSIS-1 was installed on the International Space Station (ISS) after launching on a SpaceX Falcon 9 on 15 December 2017. The orbit of the ISS permits observations not offered by standard satellites.

"TSIS-1 extends a long data record that helps us understand the Sun's influence on Earth's radiation budget, ozone layer, atmospheric circulation and ecosystems and the effects that solar variability has on the Earth system and climate change," said Dong Wu, TSIS-1 project scientist at NASA's Goddard Space Flight Center, in a statement in March.

The Japan Aerospace Exploration Agency (JAXA) also has an initiative called the Global Change Observation Mission (GCOM) and, on 23 December 2017, it launched the GCOM-C1 satellite, nicknamed SHIKISAI, which is aimed at forecasting future global climate trends. Collecting data on clouds, aerosols, ocean colour, vegetation and snow and ice, the satellite is expected to gather a complete picture of the Earth every two to three days.

In October 2017, a new Earth observation project, backed by £75,000 in study phase funding, from the UK Space Agency was announced. The TARDiS (Terahertz Atmospheric/Astrophysics Radiation Detection in Space) is designed to offer new insights on how the composition of the atmosphere is affected by climate change. The instrument is designed to fit on to the new Bartolomeo platform on the ISS. Built by Airbus, the platform is due attach to the European Columbus module of the ISS in mid-2019, and will play host to instruments from space agencies and private companies covering a wide range of applications including robotic, astrophysics and, of course, Earth observation.

"The development of TARDiS, based on novel and ground-breaking Terahertz sensing technology, will not only enable us to measure the global distribution of atomic oxygen in the upper atmosphere and to understand how this region affects the climate of Earth, but will also help us better comprehend the process of star formation and the origin of the universe," said Dr Jolyon Reburn, head of the Earth Observation Division at RAL Space in a statement announcing the project.

Like ESA, NASA combines its climate data from space with information gathered on the ground to create as full a picture as possible of changes in the Earth's environment.

"The datasets that we produce – we make them publicly available for anyone else to use," says Shepherd, whose team produces measurements on how much ice has been lost from Antarctica and Greenland for ESA's CCI. "We make use of them ourselves for scientific purposes and we also deliver them to third parties as operational datasets. For example, the sea level rise estimates are part of the European Environment Agency's climate indicator series, and they were formerly part of the EPA's [United States Environmental Protection Agency's] climate indicator series – before it was abolished by the present Administration," Shepherd tells **All About Space**.

Since the beginning of Trump's Presidency, the EPA's website has been altered to scrap various mentions of climate change and related data and also makes remaining information harder to find, leading to accusations of scientific censorship. Actions like this make maintaining climate change awareness among the public even more difficult. One way in which the space agencies are trying to counteract this is with education apps like ESA's Climate From Space iPad app, which puts over 30 years of data at your fingertips with interactive globes and maps. NASA also has a series of apps designed to spread the climate change message, including Images of Change, which shows before-and-after images of global climate phenomena. Aside from ensuring ongoing awareness, another major challenge for climate experts is funding.

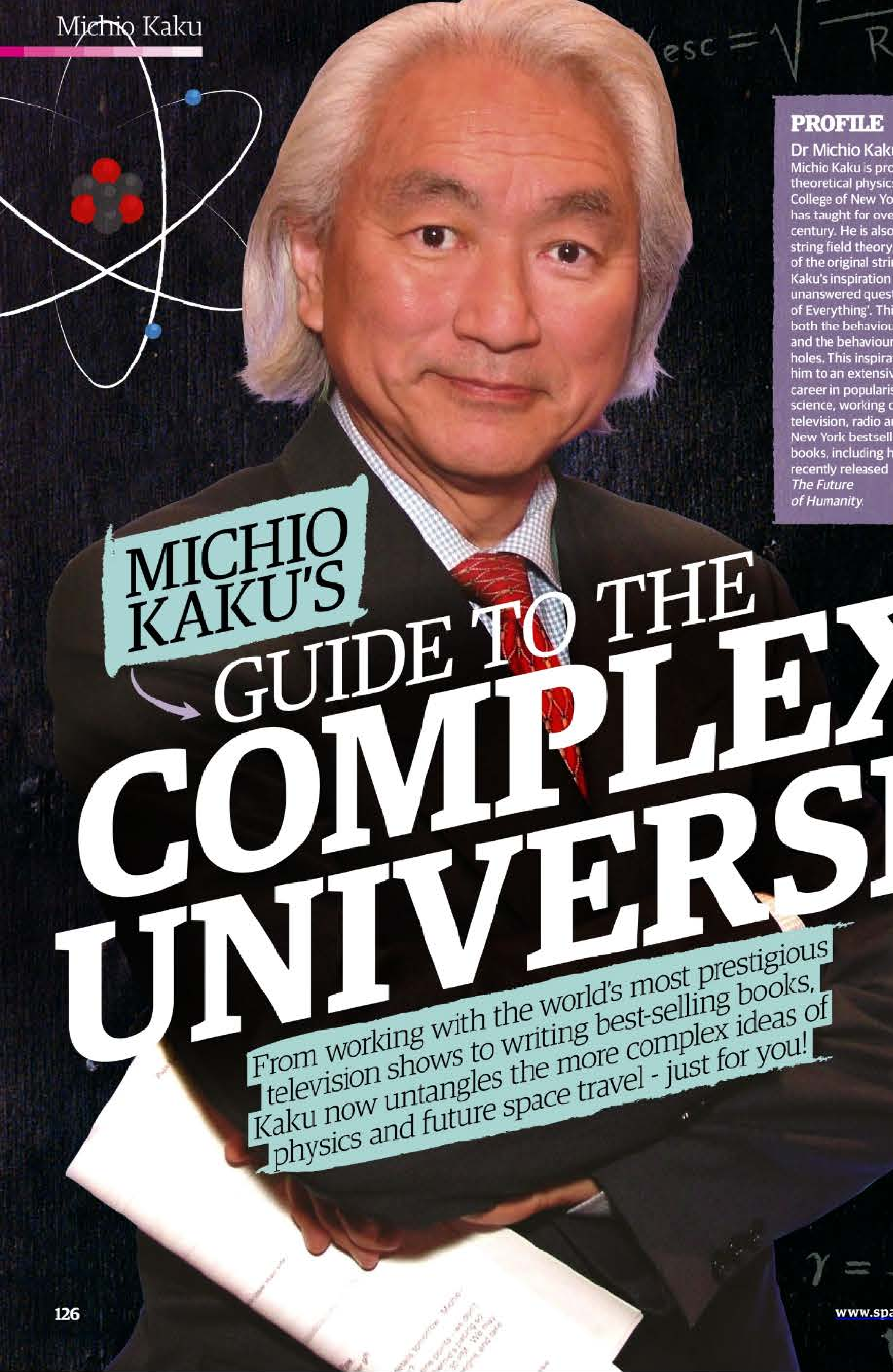
"We are working with ESA and the European Commission to try and get a successor to the CryoSat mission, which we rely heavily on," said Shepherd. "This is particularly important to us because it's the only satellite designed to look at the polar regions. It flies really close to the poles while all the other satellites that we've used, fortuitously, see part of the Antarctica and Greenland, but their scope is limited."

The good news is that a major spending bill recently passed by US Congress gives NASA $20.736 billion for 2018, thus restoring a number of Earth-science missions that were targeted for cancellation by the White House, including CLARREO (Climate Absolute Radiance and Refractivity Observatory), which is designed to help detect climate trends and improve climate prediction models. Continued investment across the globe is absolutely essential to keeping climate change at bay. After all, space is our window to the world.

> "[CryoSat] is particularly important to us because it's the only satellite designed to look at the polar regions" **Prof Andrew Shepherd**

Polar bears are one of many animals that face extinction if climate change goes unchecked

© NASA; ESA; Wolfgang Kaehler/Getty Images



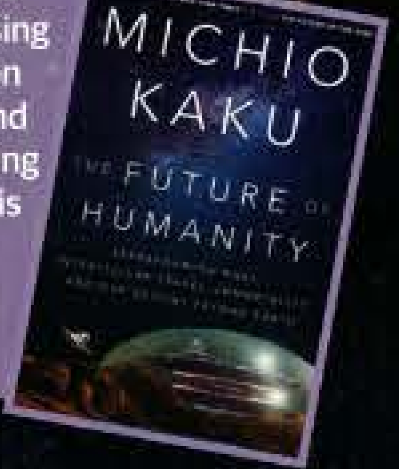
MICHIO KAKU'S GUIDE TO THE COMPLEX UNIVERSE

From working with the world's most prestigious television shows to writing best-selling books, Kaku now untangles the more complex ideas of physics and future space travel - just for you!

PROFILE

Dr Michio Kaku

Michio Kaku is professor of theoretical physics at the City College of New York, where he has taught for over a quarter of a century. He is also co-founder of string field theory, a sub-branch of the original string theory. Kaku's inspiration was Einstein's unanswered quest for the 'Theory of Everything'. This would explain both the behaviour of particles and the behaviour of black holes. This inspiration has led him to an extensive career in popularising science, working on television, radio and New York bestselling books, including his recently released *The Future of Humanity*.



There are four fundamental forces in the cosmos. Why are they important?

The universe is ruled by four fundamental forces.

We have the electromagnetic force, which lights up our cities. It's responsible for light bulbs, televisions, radio and the entire electromagnetic spectrum. Then we have gravity, which holds the Sun together, it holds the Solar System together and keeps your feet on the ground. Then we have the two nuclear forces, the weak force governs radioactive decay, and the strong force holds the protons and nucleons together.

Together they comprise all the forces known about the universe.

$E=mc^2$

Weak

An incredibly small force, it causes the ejection of subatomic particles and transformation of an element. This force results in phenomena such as beta decay.

Gravity

An attractive force with the farthest reach. Gravity is what keeps the planets orbiting the Sun and keeps our feet planted firmly on the surface of the Earth.

Electromagnetism

Controls the electromagnetic spectrum, from radio waves to gamma rays. This force ensures the interactions between electric forces.

Strong

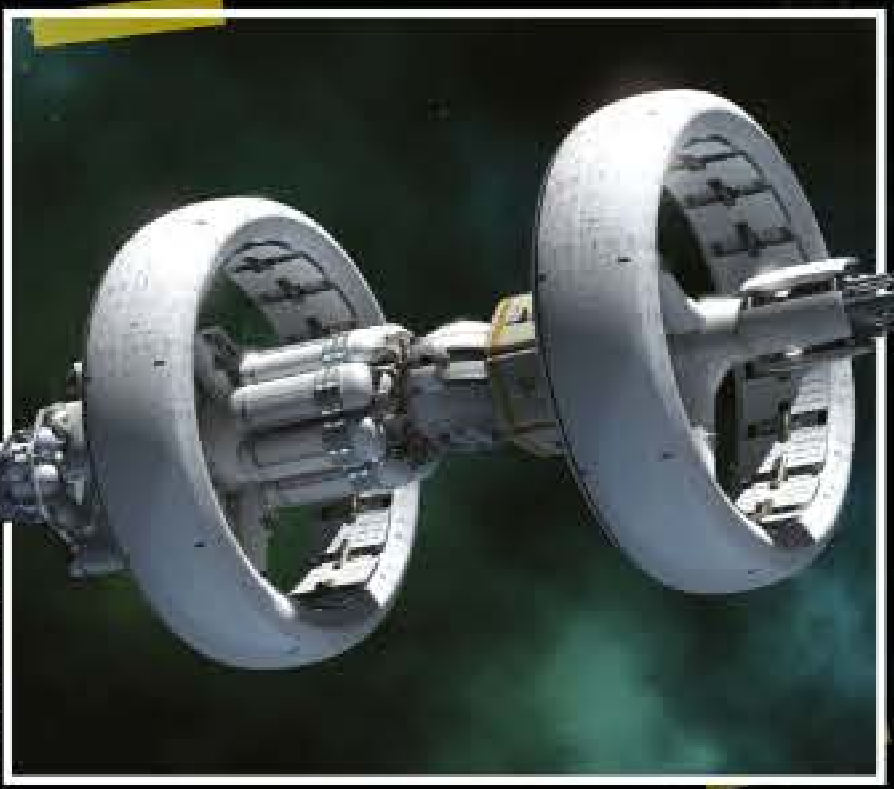
The force that keeps neutrons and protons bound together, it's considered to be the strongest among the four forces.

Do you think that the warp drive will ever be possible?

Einstein said it is very difficult to break the light barrier [the speed of light]. To have a rocket go up to the speed of light you have to have fusion rockets, anti-matter rockets and maybe ramjet fusion rockets.

But to exceed the speed of light you have to invoke general relativity, and you have to have enormous amounts of energy. Energy that is comparable to an exploding star or a black hole. There is a possibility that if you can harness this vast amount of positive energy, you can open a gateway through space and time. However, you would need negative energy to stabilise it.

So if you have this rare combination of positive energy to open up the gateway, and negative energy to stabilise the gateway, then warp drive may – just may – become possible.



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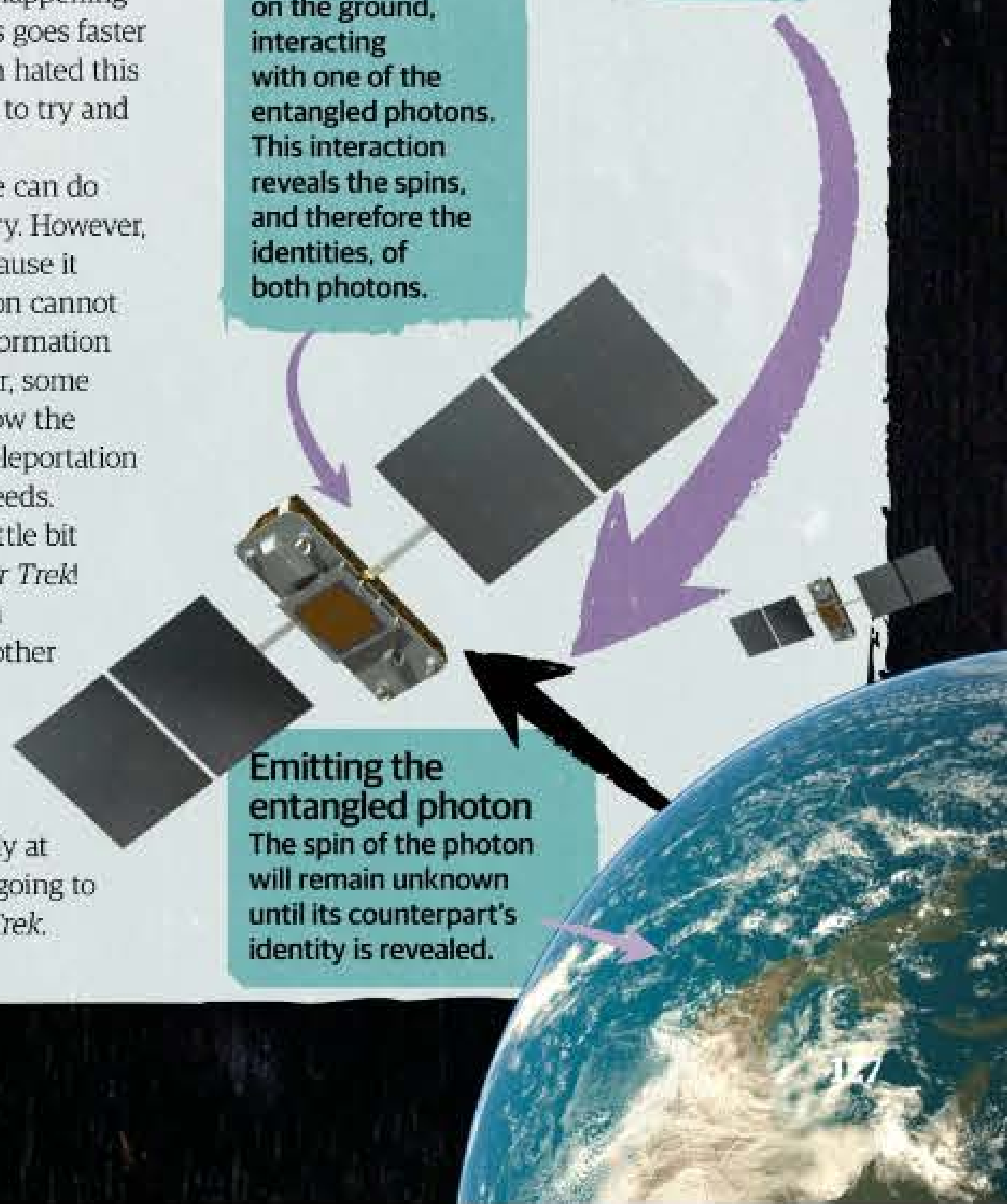
The Alcubierre warp drive, named after Mexican physicist Miguel Alcubierre, could allow us to harness enough energy to exceed the speed of light

What is quantum entanglement, especially in terms of teleportation?

If I have two electrons arriving in unison and then separate them an invisible umbilical cord emerges, connecting the two together. So that if I jiggle one [particle], the other particle somehow senses the presence of what is happening to its twin. This sensing process goes faster than the speed of light. Einstein hated this process, and he actually used it to try and disprove quantum mechanics.

Well, Einstein was wrong. We can do this experiment in the laboratory. However, Einstein had the last laugh, because it turns out that usable information cannot be transferred this way. The information transmitted is random. However, some scientists say that if you go below the speed of light, then quantum teleportation may be possible at sub-light speeds.

Quantum teleportation is a little bit different to what you see in *Star Trek*! We're talking about information travelling from one point to another point. We've done this with atoms and photons, we can teleport particles over hundreds of feet. So quantum teleportation is possible, but only at the subatomic level. You're not going to have a transporter like in *Star Trek*.



The journey remaining unknown

The photon, travelling away from Earth, most likely to an orbiting satellite, can travel vast distances in its state of confusion.

Revealing the identity

A third photon can be introduced on the ground, interacting with one of the entangled photons. This interaction reveals the spins, and therefore the identities, of both photons.

Emitting the entangled photon

The spin of the photon will remain unknown until its counterpart's identity is revealed.

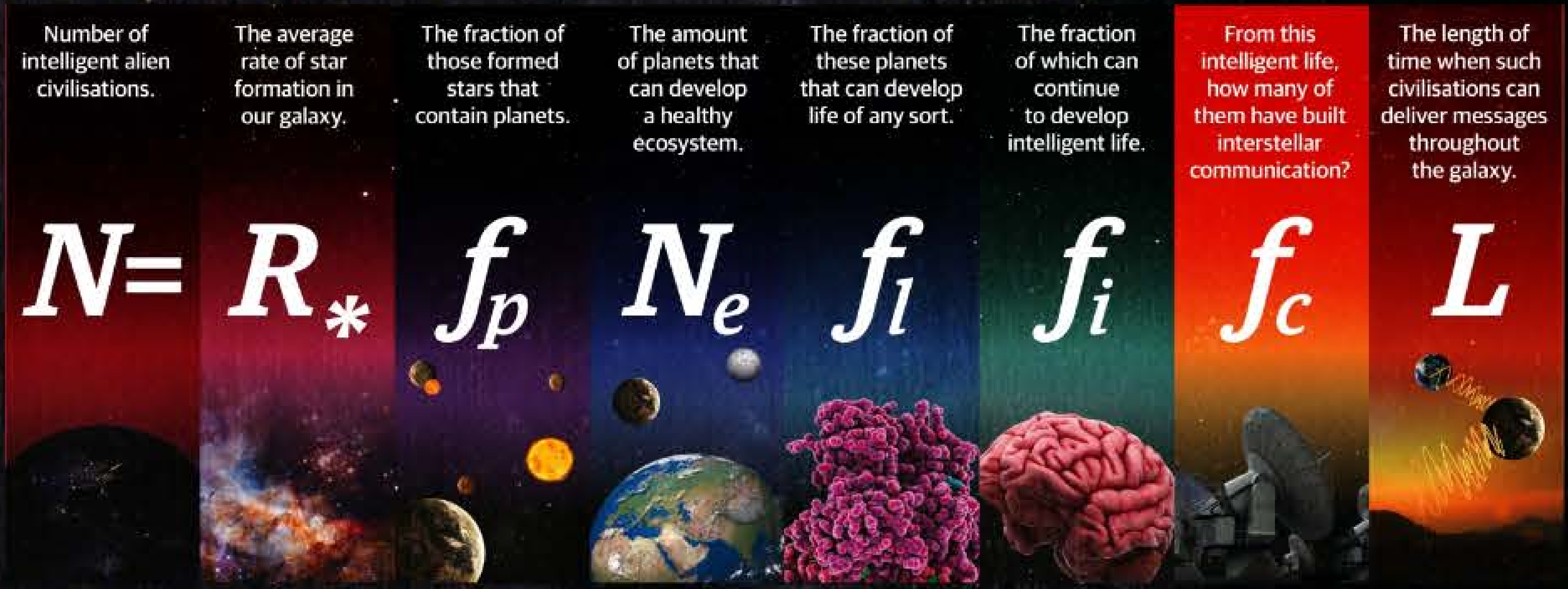
Do you think that life could exist elsewhere in the cosmos?

If you believe that the galaxy is teeming with Earth-like extrasolar planets, then you have to ask a very valid question: could there be intelligent life? In this case, why don't they visit us? Why don't they land on the White House lawn and give us the benefits of advanced technologies?

Well my attitude is this, if you're travelling in a forest and you meet the deer and the squirrels, do you talk to them? Well, yes. Initially you may want to talk to the squirrels and the deer, but eventually you lose interest because they don't talk back to you. They have nothing to offer you, so you leave them alone. I think for the most part, an advanced civilisation would view us like squirrels or deer in the forest.

Also, if you meet an anthill in the forest, do you go down to the ants and say: "I bring you trinkets. I bring you beads. I give you nuclear energy. Take me to your ant queen"? Or maybe, you have this politically incorrect urge to step on a few of them. I think that if they're that advanced that they can travel thousands of light years to reach the planet Earth, then we humans really don't have much to offer them. We're rather boring to them.

Now some people say they could be dangerous and they could be hostile. Maybe, but I don't think so. I think that if they're that advanced, they'll leave us alone. But what about plunder? They could come and plunder the Earth. Well there are a lot of planets out there with nobody on them, so you can plunder those planets much easier than plundering a planet with restive natives on it. So I think, for the most part, they'll leave us alone.



$$N = R_* f_p N_e f_l f_i f_c L$$

N	Number of intelligent alien civilisations.
R_*	The average rate of star formation in our galaxy.
f_p	The fraction of those formed stars that contain planets.
N_e	The amount of planets that can develop a healthy ecosystem.
f_l	The fraction of these planets that can develop life of any sort.
f_i	The fraction of which can continue to develop intelligent life.
f_c	From this intelligent life, how many of them have built interstellar communication?
L	The length of time when such civilisations can deliver messages throughout the galaxy.

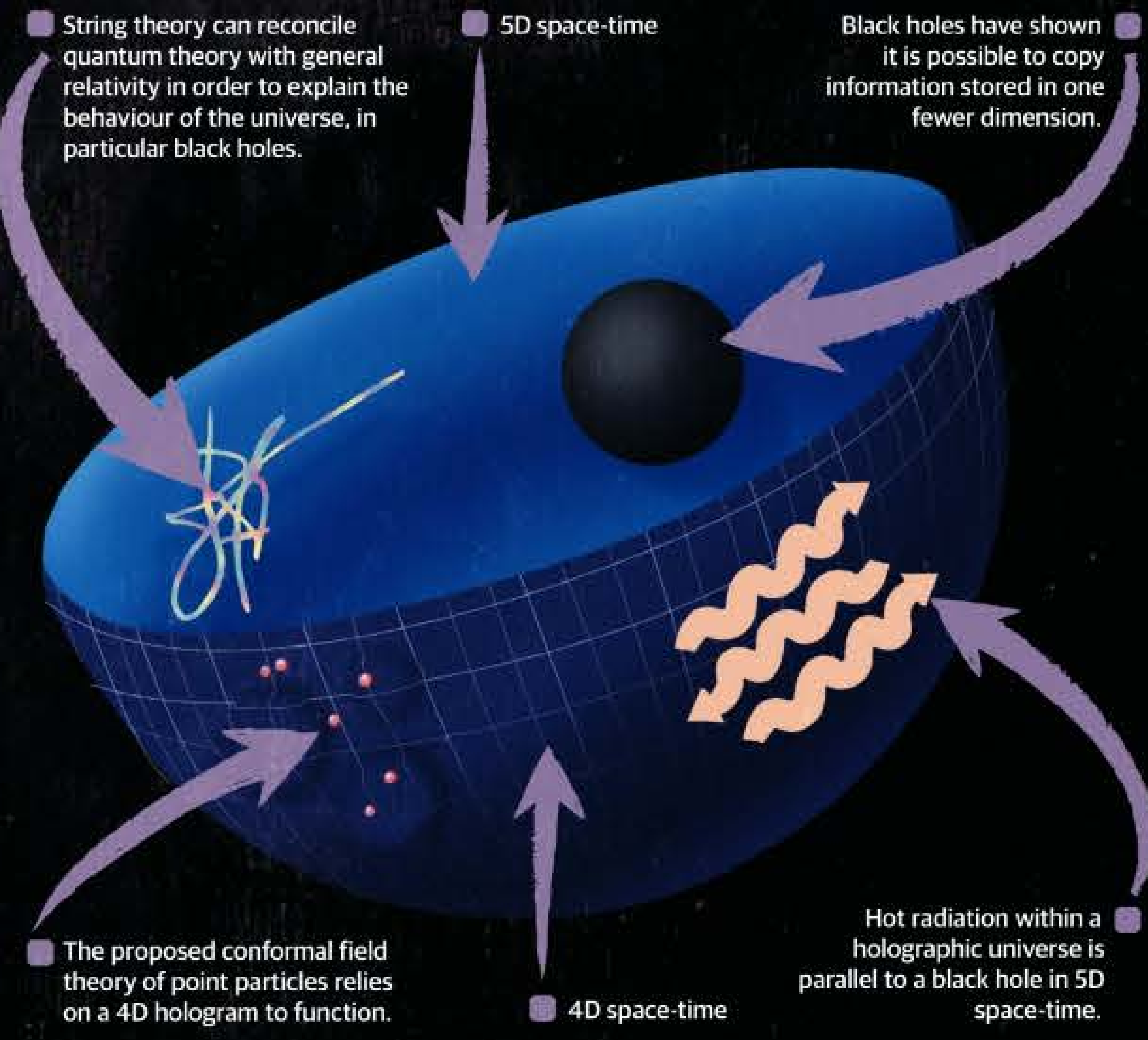
Is it possible that we're living in a simulation?

There are several interpretations of that. Some people think that reality may be a simulation, like in *The Matrix*. I don't think so.

First of all, using Newton's laws, and assuming that the atmosphere is composed of tiny little marbles instead of atoms, the world's largest computer could not simulate the atmosphere. It's too complicated. The smallest object that can simulate the weather is the weather itself. Therefore weather is 'unsimulatable', as it has too many particles.

Quantum mechanics makes it incidentally worse, because now, instead we have billiard balls representing atoms. Atoms can also spin up, spin down and spin sidewards simultaneously. So it becomes a nightmare trying to simulate quantum mechanics and the motion of particles.

Therefore I do not believe that we are in a simulation. I don't think there is a super CD-ROM where if you push the play button then here we are having this conversation. I think quantum mechanics is simply too complex, with too many possibilities, so that reality can be reduced to a CD-ROM and somebody hit our play button.



String theory can reconcile quantum theory with general relativity in order to explain the behaviour of the universe, in particular black holes.

5D space-time

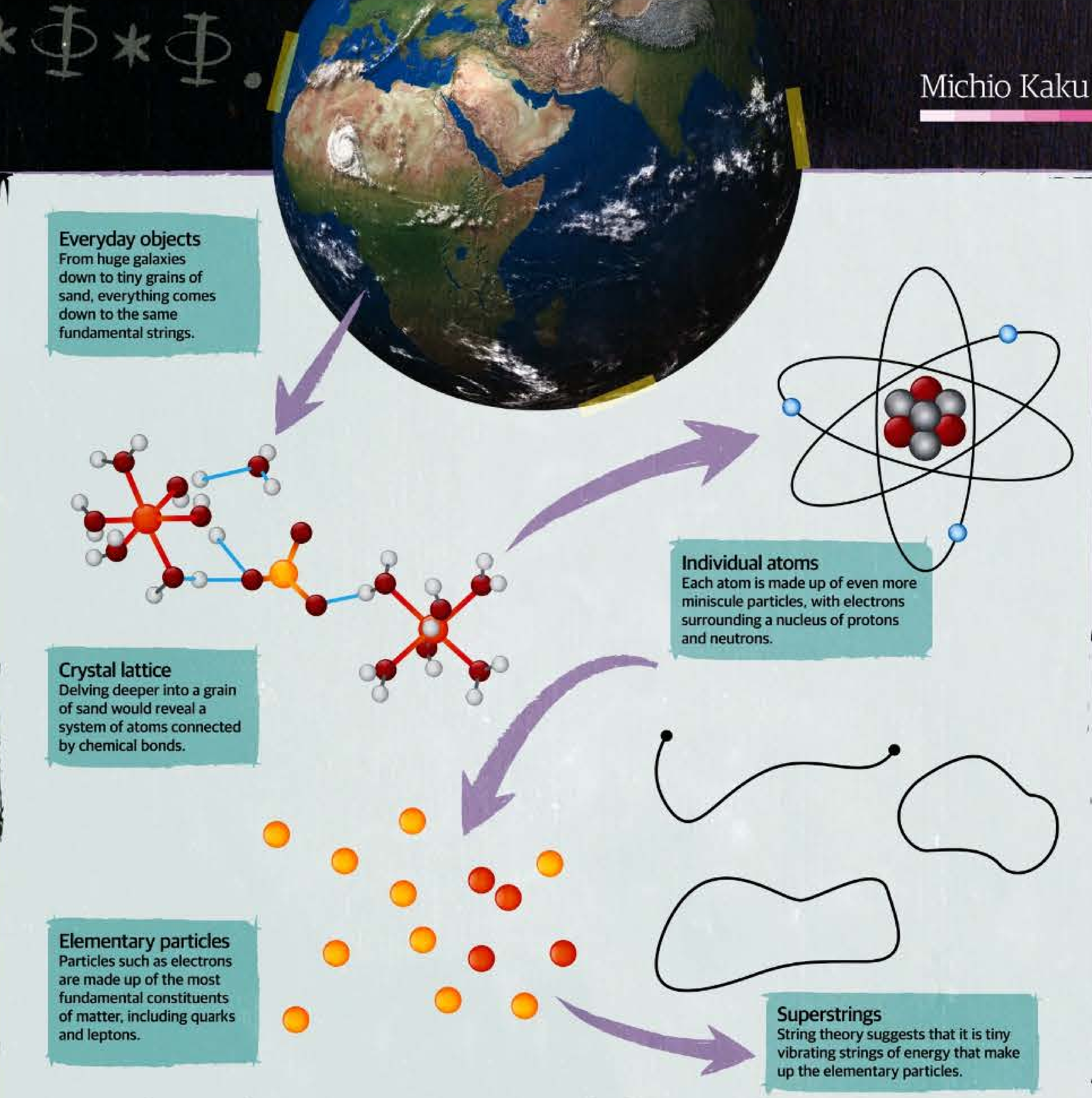
Black holes have shown it is possible to copy information stored in one fewer dimension.

The proposed conformal field theory of point particles relies on a 4D hologram to function.

4D space-time

Hot radiation within a holographic universe is parallel to a black hole in 5D space-time.

© NASA/ESA; Adrian Mann; Tobias Roetsch; Sebastian Kaulitzki / Alamy Stock Photo; Laguna Design/Science Photo Library



Everyday objects
From huge galaxies down to tiny grains of sand, everything comes down to the same fundamental strings.

Crystal lattice
Delving deeper into a grain of sand would reveal a system of atoms connected by chemical bonds.

Individual atoms
Each atom is made up of even more miniscule particles, with electrons surrounding a nucleus of protons and neutrons.

Elementary particles
Particles such as electrons are made up of the most fundamental constituents of matter, including quarks and leptons.

Superstrings
String theory suggests that it is tiny vibrating strings of energy that make up the elementary particles.

What is string theory? Why is it considered to be the theory of everything?

String theory is a single equation that allows us to summarise all the laws of the universe. Einstein spent 30 years of his life chasing after the theory of everything. He wanted an equation no more than one inch long that would allow us to "read the mind of God".

We have two great theories of the universe. We have the quantum theory, the theories that are very small, which give us lasers and atomic bombs and iPods and iPads and the Internet. That's the quantum theory, the theory of the very small. Then we have the theory of the very big. Einstein's theory of gravity and black holes and Big Bangs, but these two theories hate each other. These two theories don't like each other, so why would nature create a left hand and a right hand that don't talk to each other? That's crazy!

So we think that there is one theory that unifies the quantum theory with relativity, and that is string theory. Why do we have so many particles? We have electrons, neutrons and neutrinos. We spend billions of dollars building atom smashers to find more and more particles. [There are] 36 quarks and 19 free parameters in the standard model, and we think that all these subatomic particles are nothing but musical notes. Musical notes on a tiny vibrating string, and what is physics? Physics is harmonies, the laws of harmonies of tiny vibrating strings, that's physics. What is chemistry? Chemistry is nothing but the melodies. The melodies you can play when these strings bump into each other, creating molecules. What is the universe? The universe is a symphony, a symphony of strings, so then what is "the mind of God"? The mind of God is cosmic music resonating through 11-dimensional hyperspace.

What is matter? Why do we have planets and stars and galaxies? Why is there life and Deoxyribonucleic acid (DNA)? It's nothing but music. Music is the only paradigm rich enough to explain electrons, neutrinos, protons, DNA, stars and galaxies. It's the only paradigm rich enough to explain the universe, and that's what string theory is. String theory is considered to be the theory of everything, explaining that we are nothing but musical notes and melodies played beautifully on vibrating strings.

What is it about SpaceX's Falcon Heavy that sets it apart from other rockets we've launched beyond the Earth's atmosphere?

First of all, thousands of people lined up to watch the historic launch of the Falcon Heavy. Millions watched it online, and it was historic because this was no ordinary rocket: it was a Moon rocket, fully capable of carrying the [SpaceX] Dragon capsule around the Moon for the first time in [almost] 50 years.

We now have a Moon rocket which has been tested that can do this. Secondly, it was paid for by private funds. The United States taxpayers didn't pay one dime towards this rocket.

Thirdly, the boosters were reusable. Just like the reusable car market after World War II. A lot of the soldiers came back from war and could not afford to buy a car, because they were so expensive. The used car market opened up car ownership. It changed our culture and it can change rocket prices in the same way; they drop by a factor of ten if we have reusable booster rockets.

$260 million / £185 million

How much more a Delta IV Heavy launch costs compared to SpaceX's Falcon Heavy

Will the Falcon Heavy have a worldwide impact on space exploration?

What's new about the Falcon Heavy is that the cost of space travel is dropping dramatically. The movie *The Martian*, starring Matt Damon, cost over $100 million (£71 million). That's more than the cost of the Indian Mars rocket that reached Mars in 2014!

In other words, a Hollywood movie now costs more than a space program. So they should give Oscars to the best supporting space probe! That's how much costs have dropped.

The Chinese want to put the Chinese flag on the Moon. The Indians have already gone to Mars. We're talking about a whole new ball game with prices dropping dramatically, and that's why I think we're entering a new golden age of space travel.

© NASA, SpaceX, Aidan Monaghan

7 December 1972

The last time the human race visited the Moon, as part of the Apollo 17 mission

Why is the escape velocity an important factor in launchg it?

Well, using Newton's laws of motion and gravity we can calculate that to orbit the Earth, you have to go at about 18,000 miles per hour [29,000 kilometres per hour].

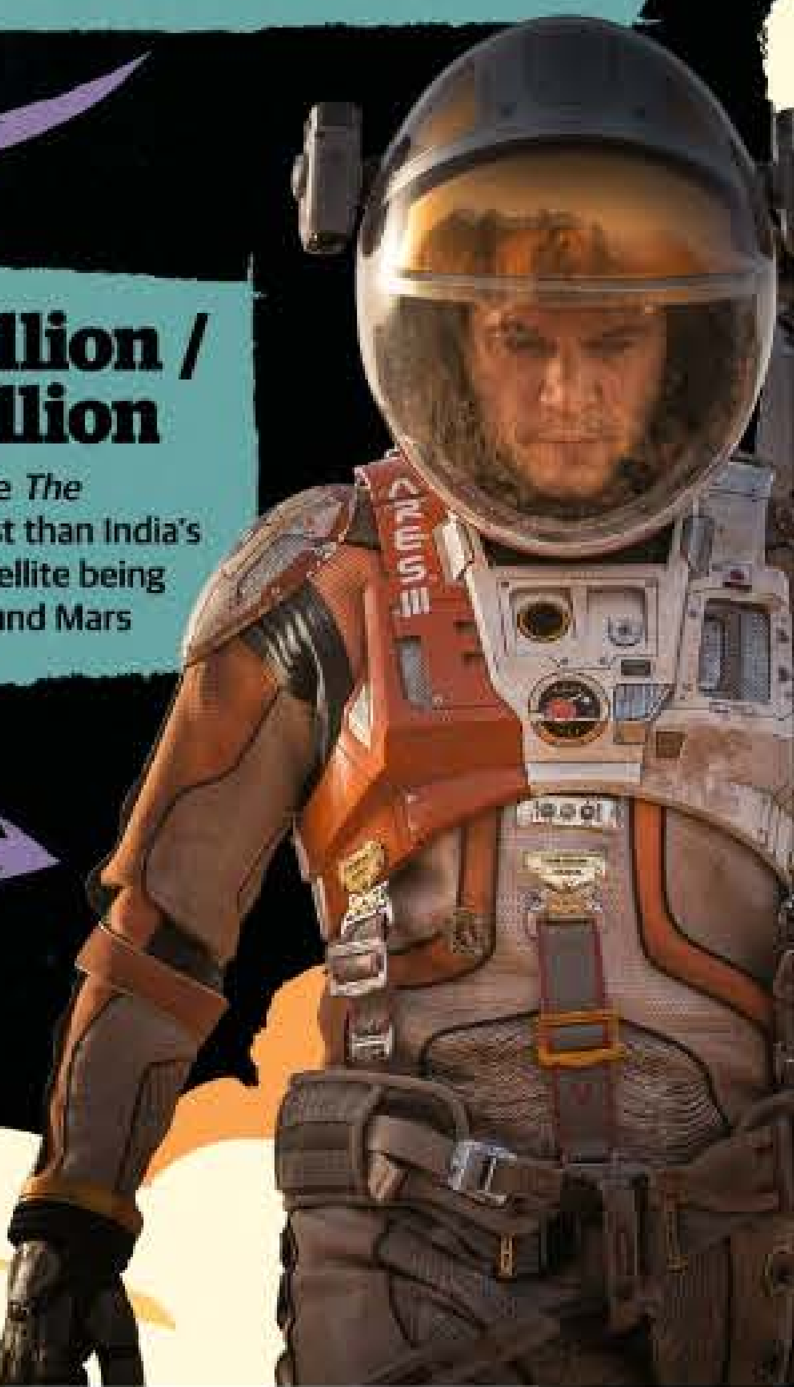
To escape the gravitational field of the Earth you have to go about 25,000 miles per hour [40,000 kilometres per hour]. So every Moon rocket [in this case, the Falcon Heavy] has to have a velocity of at least 25,000 miles per hour in order to escape Earth.

25,000 miles per hour / 40,000 kilometres per hour

The speed that Falcon Heavy must go in order to escape the orbit of Earth

$35 million / £25 million

How much more *The Martian* film cost than India's Mangalyaan satellite being put in orbit around Mars



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BREWING BEER IN SPACE

WRITTEN BY LEE CAVENDISH

© NASA

With Budweiser's intention to make itself the beer of Mars, **All About Space** digs a little deeper into its beneficial implications

The formidable task of putting humans on the surface of Mars seems to be very newsworthy at the moment, especially with the surging efforts of SpaceX, Virgin Galactic and NASA. These organisations have a long-withstanding desire to, once again, go where no man has gone before. But with all these efforts being made in an attempt to travel to Mars, another organisation has already started to plan for the momentous occasion. Last year, the international lager distributor Budweiser announced its aim to make its 142-year-old product the 'beer of Mars.'

"With this bold, new dream Budweiser is celebrating the entrepreneurial spirit in which our iconic brand was founded upon. Through our relentless focus on quality and innovation, Budweiser can today be enjoyed in every corner of the world, but we now believe it is time for the 'King of Beers' to set its sights on its next destination," says Ricardo Marques, vice president of marketing at Budweiser. "When the dream of colonising Mars becomes a reality, Budweiser will be there to toast the next great step for mankind."

Much like every other great ambition in the world, results will not be achieved without significant challenges. It is one thing to put humans on Mars and colonise the harsh, dry planet, but brewing an alcoholic beverage that has been around for nearly a century-and-a-half brings a unique set of obstacles. Although some people say it isn't necessary to have beer in space or on a different planet, it still provides an intriguing task that could have enduring effects on space agriculture and water extraction in extraterrestrial environments.

On 21 November 2017, Anheuser-Busch, the parent company of Budweiser, announced they were taking the first steps in upholding their commitment of being the first beer on Mars. This announcement outlined its plan to conduct two experiments on the most unique laboratory humans have ever created, the International Space Station (ISS). Budweiser partnered up with the Center for Advancement of Science in Space (CASIS), a non-profit organisation that manages the United States National Laboratory on the ISS. With the research facility available for use, Anheuser-Busch then had to prepare the two experiments to be sent, which led to an additional collaboration with Space Tango.

Space Tango is a payload development company that created its own CubeLab modules and which will house the two individual experiments. These include a handful of barley seeds in each cube, as barley is a key ingredient in the production of the world's most popular lagers. On 15 December 2017, SpaceX launched its 13th resupply mission to the ISS, shooting a Dragon capsule with about 2,177 kilograms (4,800 pounds) of research equipment, including these ever-so precious barley experiments into space.

In one cube, the barley seeds will be left in storage to see what happens when they're exposed to a microgravity environment for a month. In the other cube, the seeds will be fed and watered over the same period to see how they grow in the same research facility, also known as seed germination. On Earth, barley will grow between six and ten inches (15 to 25 centimetres) in two weeks, but who knows what length it could grow to without the constraints of gravity restricting its development.

With the journey to the Red Planet taking roughly seven months, the effects of microgravity as they are hurtling through space could cause major damage to the ingredients. This is not only upsetting - as you can no longer have a cool refreshing alcoholic drink on a different planet - but it is also highly inefficient, as worthless baggage means wasted spacecraft fuel. This is why initial investigations have begun with two short-term experiments on board the relatively nearby ISS laboratory. These experiments will also play a large role in understanding how to brew the Bud once humans have colonised Mars. Mars has a diameter of 6,779 kilometres (4,212 miles), which is 53 per cent the size of Earth, and is about ten-times less massive than our home planet. This leads to a much weaker surface gravity on Mars, where it is only 38 per cent of Earth's. This would mean you'd weigh roughly a third of your Earth weight on Mars. Although our Martian probes have done a fantastic job exploring the surface, they cannot tell us what it would be like starting a farm, so to see what effect low gravity has on plant germination is vital in this research.

There have been many agricultural experiments completed on board the ISS. Throughout the years, the floating home has grown many plants and vegetables as it provides many advantages for a manned spaceflight mission. The art of growing vegetables in space would mean that the crew could minimise the amount of room taken up on the spacecraft, making it more sustainable. Not only that, but it can have a huge psychological benefit to the astronauts, providing them with an activity that gives them a sense of comfort and relaxation. When you're on a long-term spaceflight, for example a seven-month flight to Mars, these benefits can prove vital.

Dr Gary Hanning, the director of Global Barley Research for Anheuser-Busch, explained to **All About Space** that this research presents a rare opportunity to study barley in a way that can improve its quality on Earth, as well as off it: "As Budweiser works towards its goal of being the first beer on Mars, taking the first steps with barley experimentation on the Space Station [ISS] allows us to investigate various key traits, like germination, in an even more extreme environment," says Hanning. "[This is] information that is pertinent to our goals of developing high-quality malting barley here on Earth, and Budweiser on Mars."

There are complications though, as plants require a specific environment that is best suited for Earth, and not the harsh territories beyond. This list includes space (both height and between plants), nutrients for plant growth, water, a specific temperature and the appropriate light intensity. "All these present unique challenges on Mars. Those same factors are critical for barley growth on Earth," Hanning continues. "For malting, the key parameters are water, temperature and air flow. How to have those available will be important for any industry in space."

It is key to realise that the motivation to make Budweiser the go-to alcoholic drink that is on average about 225-million-kilometres (140-million-miles) away will have long-standing effects on extraterrestrial habitation, and not just for growing

> "When the dream of colonising Mars becomes a reality, Budweiser will be there to toast the next great step for mankind"

Initial barley testing

In order to test the feasibility of brewing beer in space and on Mars, two barley experiments were recently sent to the International Space Station

Seed exposure

In one of the CubeLab modules, the barley seeds will simply be kept in storage to see how they react to the microgravity environment. In an ideal situation, barley seeds are best kept in a cool and dry place, but space can lead to the exposure of cosmic rays, among other forms of unprotected radiation. This experiment will see if storage in space is possible.

Seed germination

Unlike the seed exposure experiment, these barley seeds will be watered and fed in a similar fashion to those down on Earth. On Earth, barley seeds will typically grow between six and ten inches (15 to 25 centimetres) tall, but on board the ISS the rate of growth could be extremely different.

SpaceX's Dragon capsule carrying the barley experiments returned to Earth on 13 January 2018

© NASA; Oleksii Terpugov / Alamy Stock Photo

Why beer ingredients are important for space travel

The five constituent ingredients of Budweiser are the key to growing and storing crops while travelling in space and extracting clean water on Mars

Water

1 About 90 per cent of Budwesier is water, making it the most major element of the refreshing lager. However, when you go beyond Earth it becomes a limited and sacred resource. If humans were to colonise Mars, retracting water from beneath its surface and desalinating it would become the top priority.

Rice

4 Rice is used in many dishes across the world; this is because it is a good source of carbohydrates in your diet. Carbohydrates are important in giving a person the energy to complete their everyday tasks, which can be the difference between life and death in space.

Barley

2 Not only is barley used in the production of beer, it is also used in the production of many foods that are beneficial for a human's health. The results from these barley experiments could prove to be highly influential on an astronaut's diet.

Hops

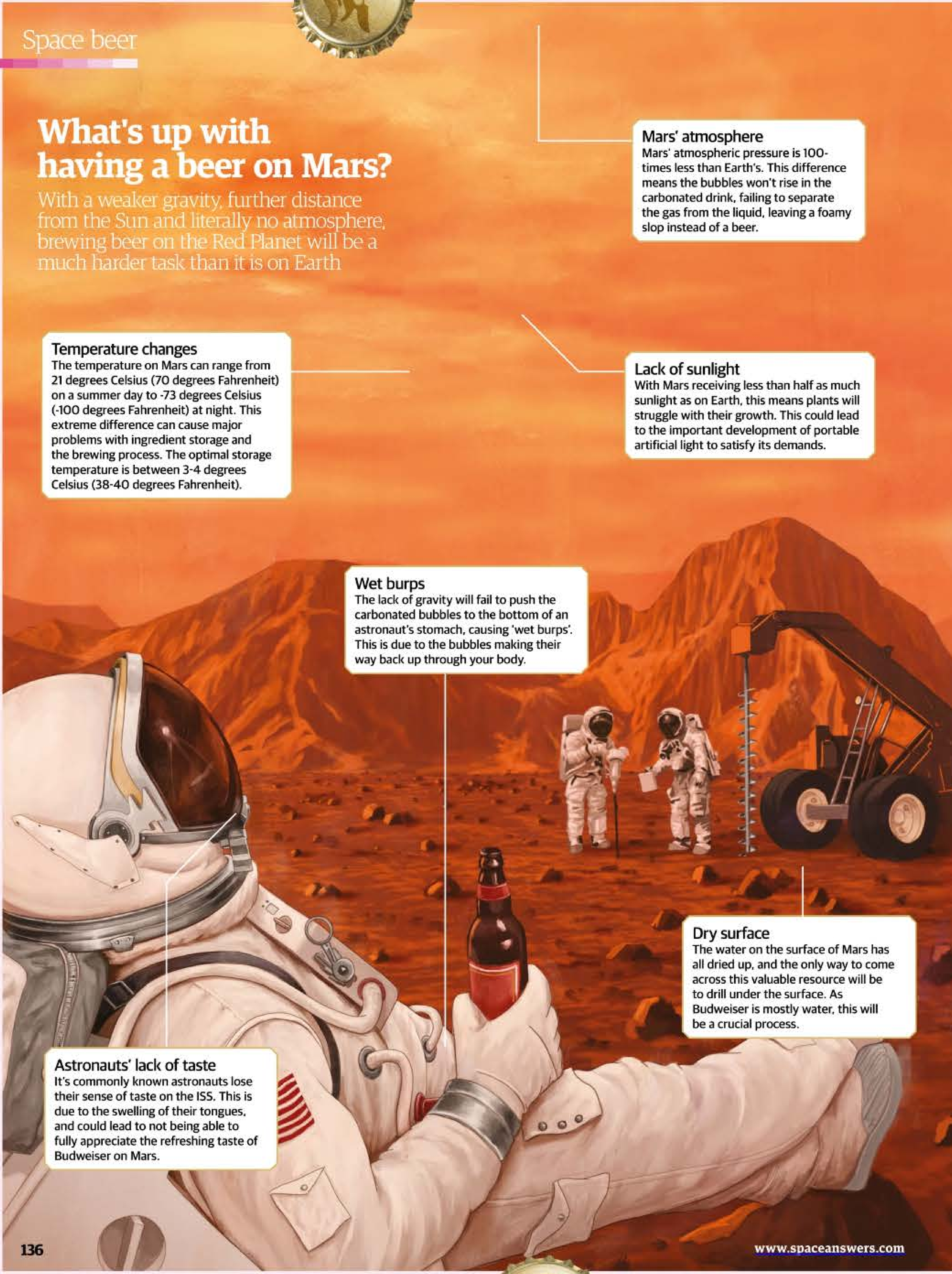
3 These flowers, like any other flowers, need sunlight, water, nutrients and room to grow. These necessities have shown to give astronauts a sense of calmness and relaxation in caring for them.

Yeast

5 Yeast and humans are about 70 per cent similar in genetics, this makes them the most ideal microbes to examine in order to see how human cells would react to wandering through space. The results have shown that space can be damaging to yeast cells, which doesn't look good for human cells.

What's up with having a beer on Mars?

With a weaker gravity, further distance from the Sun and literally no atmosphere, brewing beer on the Red Planet will be a much harder task than it is on Earth



Mars' atmosphere

Mars' atmospheric pressure is 100-times less than Earth's. This difference means the bubbles won't rise in the carbonated drink, failing to separate the gas from the liquid, leaving a foamy slop instead of a beer.

Temperature changes

The temperature on Mars can range from 21 degrees Celsius (70 degrees Fahrenheit) on a summer day to -73 degrees Celsius (-100 degrees Fahrenheit) at night. This extreme difference can cause major problems with ingredient storage and the brewing process. The optimal storage temperature is between 3-4 degrees Celsius (38-40 degrees Fahrenheit).

Lack of sunlight

With Mars receiving less than half as much sunlight as on Earth, this means plants will struggle with their growth. This could lead to the important development of portable artificial light to satisfy its demands.

Wet burps

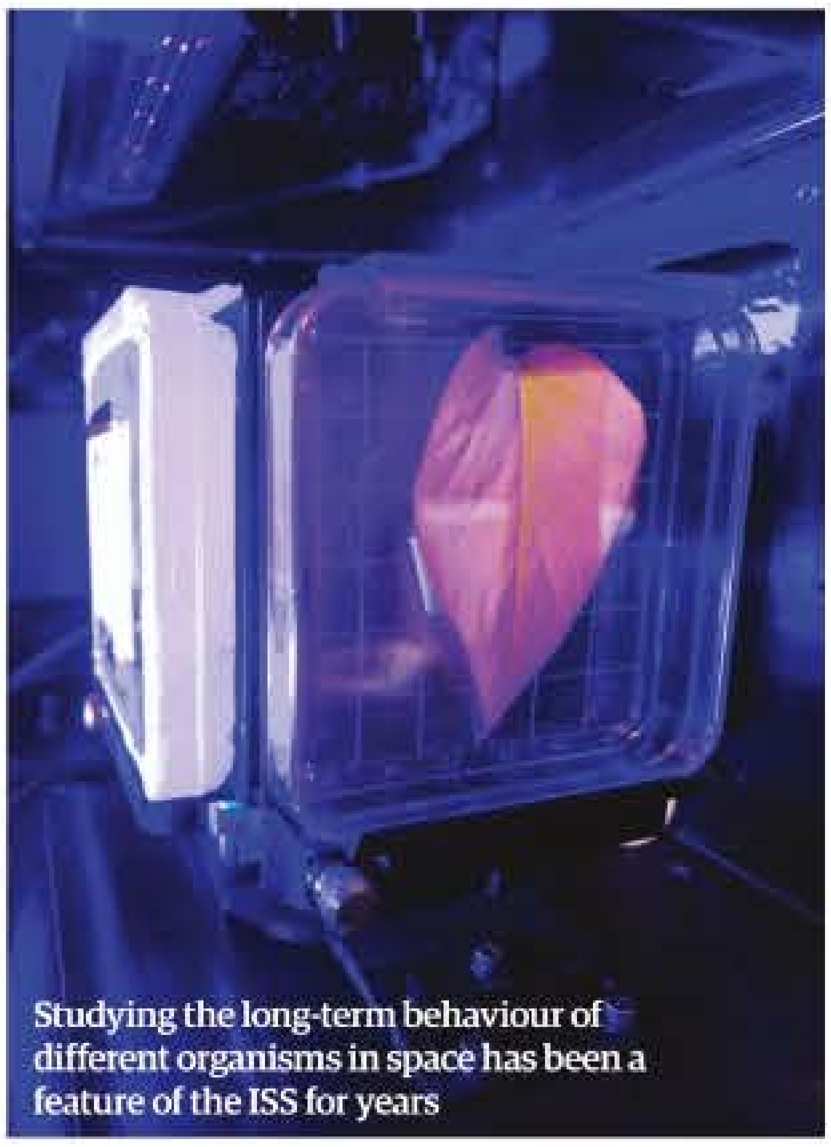
The lack of gravity will fail to push the carbonated bubbles to the bottom of an astronaut's stomach, causing 'wet burps'. This is due to the bubbles making their way back up through your body.

Dry surface

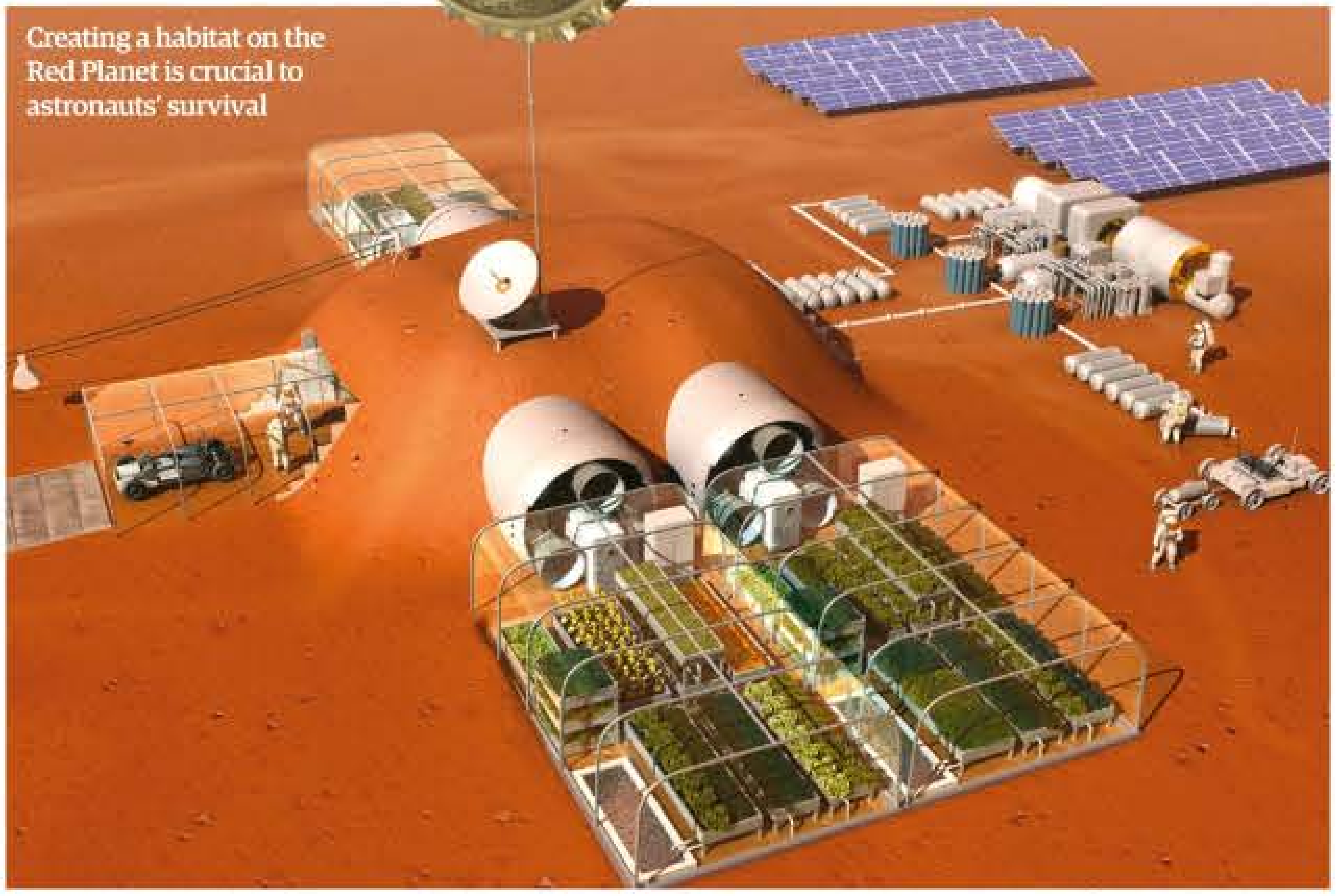
The water on the surface of Mars has all dried up, and the only way to come across this valuable resource will be to drill under the surface. As Budweiser is mostly water, this will be a crucial process.

Astronauts' lack of taste

It's commonly known astronauts lose their sense of taste on the ISS. This is due to the swelling of their tongues, and could lead to not being able to fully appreciate the refreshing taste of Budweiser on Mars.



Studying the long-term behaviour of different organisms in space has been a feature of the ISS for years



Creating a habitat on the Red Planet is crucial to astronauts' survival

food. Officials at Budweiser have outlined that they hope to tackle the issue of extracting and desalinating the water on Mars.

NASA's Mars Reconnaissance Orbiter has recently discovered eight sites of buried water ice locked away over nine metres below some steep slopes. This water could provide future explorers with an essential liquid, needed for the human race to survive on Mars. Unfortunately, Mars' inhospitable surface conditions, mean water will not exist as a liquid - as surface oceans, lakes or even puddles. As 90 per cent of Budweiser is water, it's essential to have fresh water in order to manufacture the refreshing, crisp taste in an alien environment.

Tapping into the water extracts hidden away on the Red Planet is one thing, but desalinating it and making it safe for human consumption is another. Particularly when it comes to perchlorates, which are harmful and toxic chemicals that has been proven to reside in Martian soil. Although there are processes used on Earth to desalinate water, such as swapping out the salt molecules - known as ion exchange - and pushing water through a tiny membrane to leave the harmful molecules behind - also known as reverse osmosis - there is an issue with bringing these processes to Mars. The issue with these processes is that the equipment is very fragile, and if just one piece breaks, it would take at least another six months to get a replacement out there. Nonetheless, it is still feasible.

When it comes to examining how microgravity changes different types of vegetation, yeast has already been the subject of many experiments on the ISS. Due to humans and yeast sharing 70 per cent of the same genetics, yeast has become the closest match for testing the effects of space on human cells. The results from this study showed that spaceflight could have damaging effects on the cellular processes in yeast, which could also prove harmful for our astronauts' wellbeing.

> "Plants require a specific environment that is best suited for Earth, and not the harsh territories beyond"

This degree of exposure in a harsh environment can also damage another important ingredient of Budweiser, rice. In August 2011, 100 grains of brown rice were sent to the ISS with the intention of measuring its germination rate and the affects of storage on the crop. The metal container holding the test subject was kept outside the laboratory, where it witnessed the harsh environment of space. The results showed that when half the rice was removed after 13 months, and the other half in 20 months, the rate of germination had decreased more than 48 per cent when compared to the samples taken on Earth. This proves that space travel will have a damaging effect on the rice, which will consequently have a negative effect on the beer brewing process.

The International Space Station is the best laboratory for testing how microgravity changes a subject

Hops give beer its bitter flavour, which is the gem of Budweiser's taste. To grow hops, much sunlight is needed in order to blossom. This is a problem on Mars; as the Red Planet is much further away from the Sun than Earth, it only receives less than half as much sunlight. Artificial light will become a necessity because of this predicament, and the development of artificial light will benefit many plants and crops while colonisation settles down.

The work that has already been done, and what we already know about the brewing process, has shown there are inherent problems to overcome. With all that being said, the work that is being done both here on Earth and in the ISS laboratory will provide long-lasting, important and beneficial improvements on how we counteract agricultural and water-based problems for space travel.

On the 13 January 2018, the ISS released the SpaceX Dragon cargo containing the experiments, where it splash-landed in the Pacific Ocean at 3:36pm Greenwich Mean Time (10:36am Eastern Time). "The samples are expected back in Fort Collins [Colorado, United States] later this week. Then, we will begin the genetic analysis and interpret those results. We are already in discussion with SpaceTango on the next experiments," explains Hanning, only two days after the Dragon capsule's splashdown.

When asked about what the next step is for making Budweiser the beer of Mars, Hanning replied: "We are focused on barley production. A part of that is linking with other plant scientists working in space on various aspects identified as limiting for agricultural production.

"There are many projects by other scientists focused on fluid dynamics that will benefit AB [Anheuser-Busch] when the time comes to move the micro-gravity brewing aspect ahead."

So while we wait on the preliminary results to come back concerning the barley experiments, all we can do is just sit back, close our eyes and dream about the day we can crack open a cold one on the neighbouring Red Planet, Mars.

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SPACE CHANGES HOW *YOU* THINK

Mind and body, humans are built for Earth. So what happens when we venture beyond our planet?

Written by Benjamin Skuse

© NASA; ESO / T. Preibisch

Although fundamental to the existence of life on our world, the full force of gravity on the human body slowly wreaks havoc over a lifetime. As our bodies lose their youthful vigour, gravity compresses the spine, prolapses organs and prevents blood from freely flowing upwards, to cause varicose veins and swollen limbs.

But, without it, the story could be far worse. Living in a microgravity world on the International Space Station (ISS), astronauts' bodies begin to deteriorate in a way akin to rapid ageing. Not having to support the astronaut's weight in space, the body reacts the same way it does to a sedentary lifestyle: by releasing calcium normally stored in bone into the bloodstream, causing bone loss. Extended stays on Russia's former space station Mir resulted in bone mass loss of as much as 20 per cent. Similarly, with little need to contract muscles normally used to fight the force of gravity on Earth, astronauts can lose as much as 20 per cent muscle mass on spaceflights lasting just five to 11 days if they do not counter the effects with regular exercise.

While these effects on the body are significant, perhaps the most worrying upshot of living without gravity are the changes in the brain - sometimes permanently. More than half of astronauts have experienced symptoms of what is known as vision impairment and intracranial pressure (VIIP) during long missions.

Thought to be caused by the same liquid redistribution in the astronaut's bodies that gives them puffy faces, extra fluid in the skull is believed to increase pressure in the brain and the back of the eye. This can flatten the eyeball, which pushes the retina forward and inflames the optic nerve. The result is blurred sight, and effects can lead to long-term vision deterioration.

VIIP and other symptoms are concerning, but the ISS has little space to conduct full investigations,

A photograph from the ISS shows stunning detail of much of the Atlantic coast of the United States, yet VIIP syndrome can make the view blurry for astronauts

NASA astronaut Mae Jemison demonstrates weightlessness

A participant in Seidler's bed rest study at the University of Texas Medical Branch in Galveston

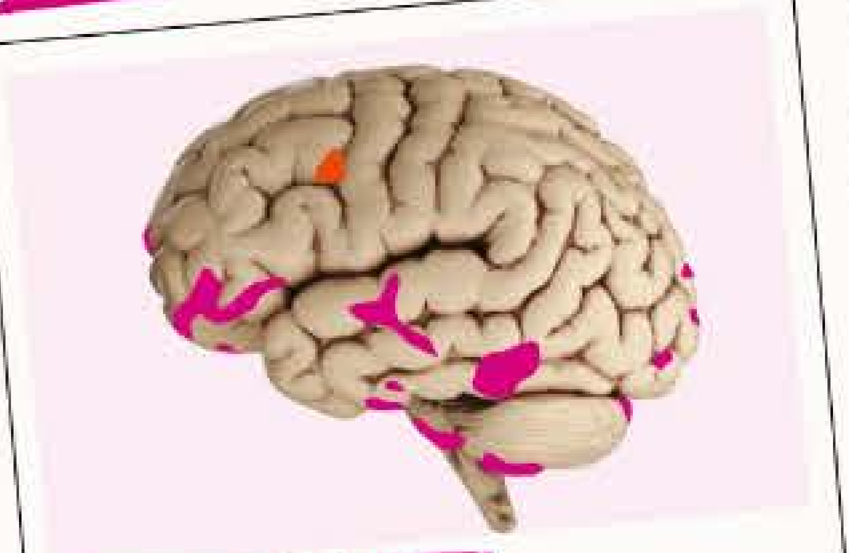
so researchers have to be inventive back here on Earth. Alongside traditional animal studies and dry immersion in water, one of the more bizarre techniques involves asking volunteers to spend time in beds that are tilted so that their feet are higher than their heads. First devised by Soviet scientists in the early 1970s, the technique is said to have been invented to combat the sensation cosmonauts experienced of slipping off the foot of the bed on return to Earth.

Now, bed tilting is used by the likes of NASA to simulate bone loss and muscle wastage, as well as the shift of body fluids towards the head. Dr Donna Roberts from the Medical University of South Carolina leads a US team that aims to understand the changes to the brain astronauts experience in spaceflight. Roberts used the tilted bed technique to mimic microgravity, asking volunteers to spend up to 90 days in beds tilted 6 degrees.

While it may sound like an absolute dream to some – watching movies, playing video games and even learning a foreign language from the comfort of a bed all day long – participants were only allowed to lift their heads on one elbow to eat, had to use bedpans to void their bowels, and took overhead showers while remaining entirely in the head-down position.

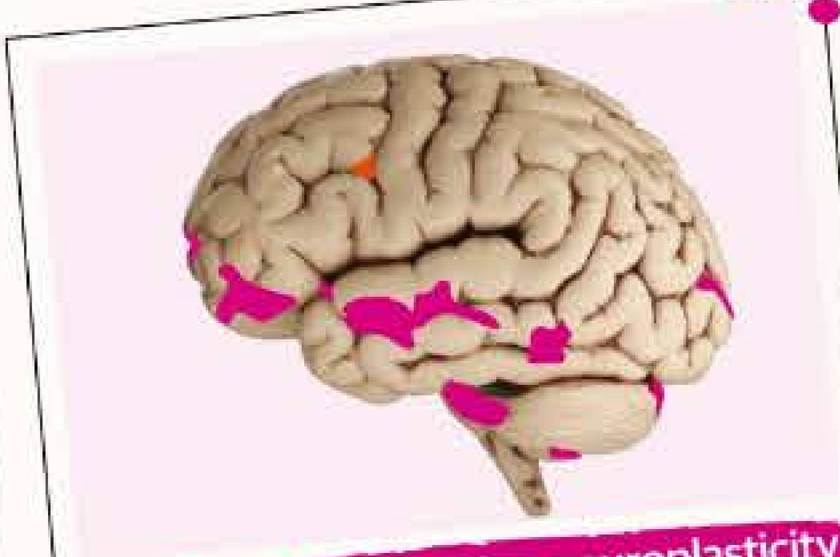
Yet the volunteers' struggles were worth it. "I did MRI scans of their brain before and after bed rest," reveals Dr. Roberts. "When I looked at their scans

How microgravity affects your grey matter



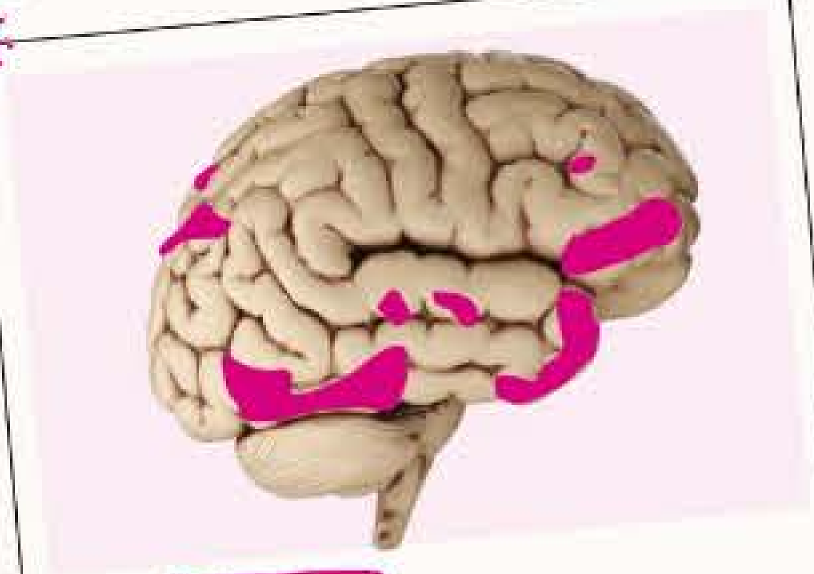
Grey matter changes

While orange marks show regions with significant grey matter volume increases, purple signifies significant grey matter decreases.



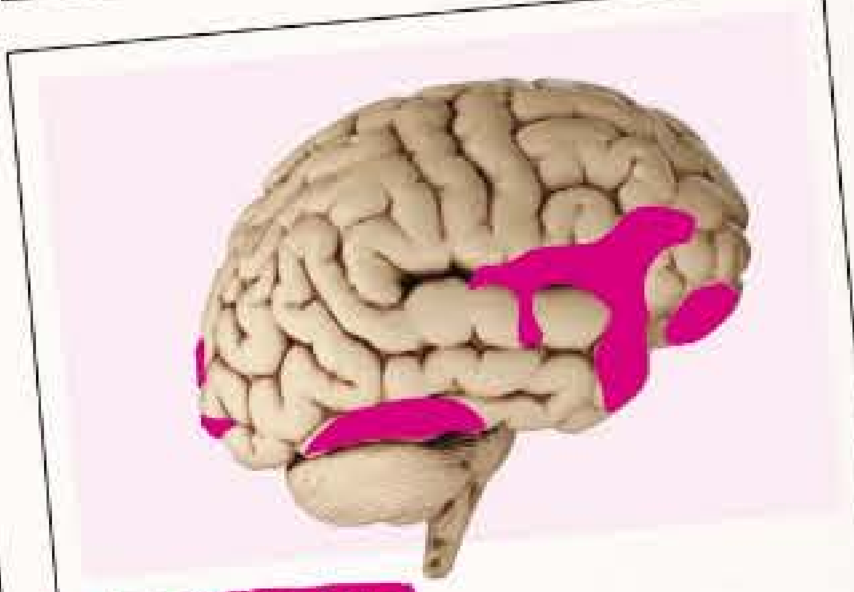
Spaceflight highlighting neuroplasticity

Increased grey matter concentration from before to after spaceflight, potentially reflecting different neuroplasticity processes.



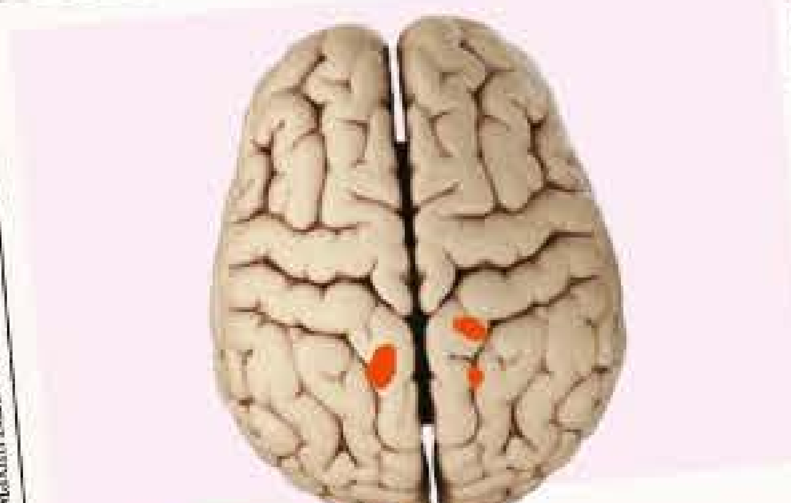
Brain shifted up

Decreased grey matter concentration from before to after spaceflight, potentially reflecting an upward shift of the brain.



Brain shifted up

Decreased grey matter concentration in a different region from before to after spaceflight, potentially reflecting an upward shift.



Controlling legs

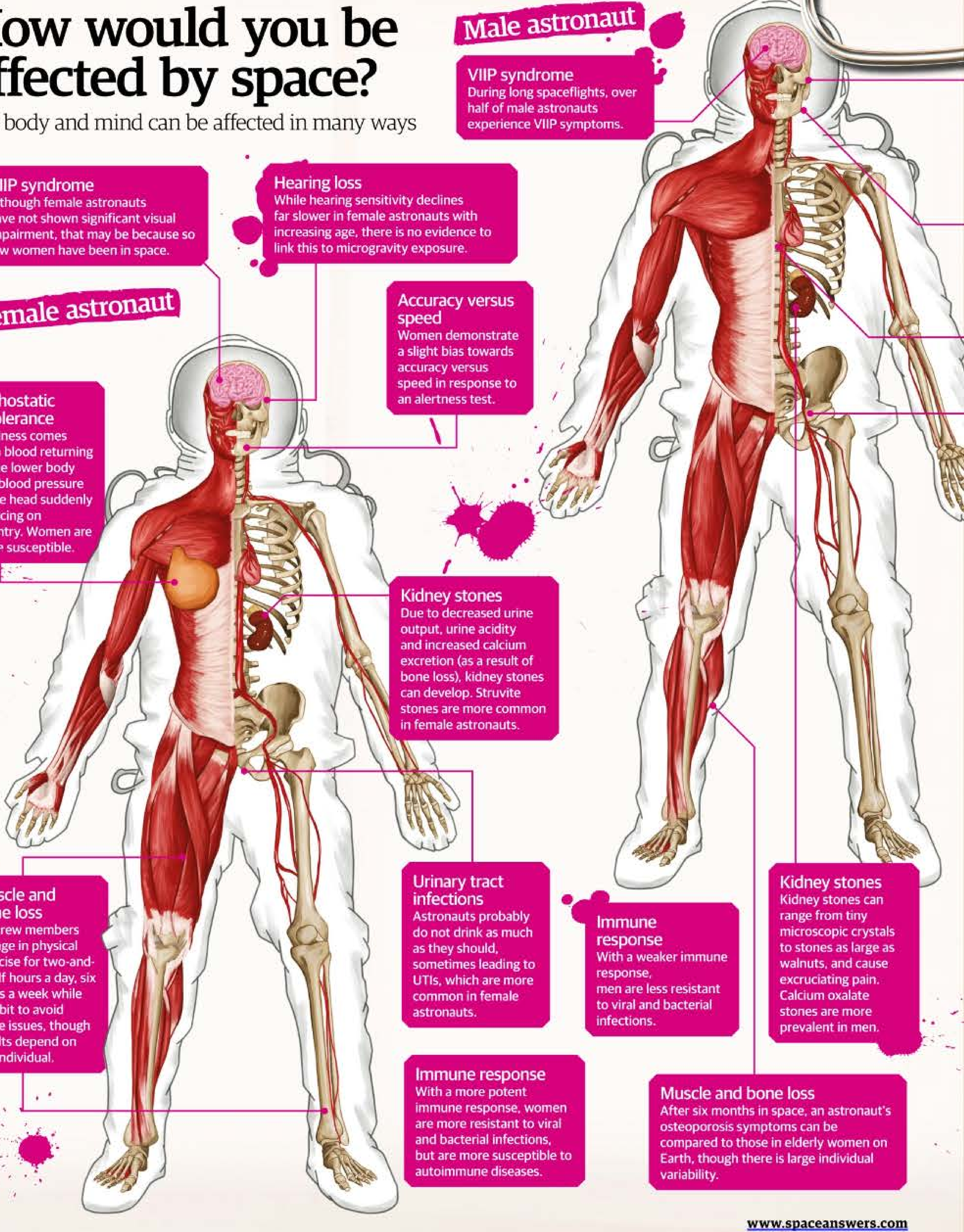
Increased concentration from before to after spaceflight in regions that process sensory input from, and control movement of the lower limbs.

Participants discuss readings of the parabolic flight Van Ombergen studied

© NASA; ESA/A. Le Floc'h; Maxim Basinski / Alamy Stock Photo

How would you be affected by space?

The body and mind can be affected in many ways



VIIP syndrome
Although female astronauts have not shown significant visual impairment, that may be because so few women have been in space.

Hearing loss
While hearing sensitivity declines far slower in female astronauts with increasing age, there is no evidence to link this to microgravity exposure.

Accuracy versus speed
Women demonstrate a slight bias towards accuracy versus speed in response to an alertness test.

Orthostatic intolerance
Dizziness comes from blood returning to the lower body and blood pressure in the head suddenly reducing on re-entry. Women are more susceptible.

Kidney stones
Due to decreased urine output, urine acidity and increased calcium excretion (as a result of bone loss), kidney stones can develop. Struvite stones are more common in female astronauts.

Muscle and bone loss
ISS crew members engage in physical exercise for two-and-a-half hours a day, six times a week while in orbit to avoid these issues, though results depend on the individual.

Urinary tract infections
Astronauts probably do not drink as much as they should, sometimes leading to UTIs, which are more common in female astronauts.

Immune response
With a more potent immune response, women are more resistant to viral and bacterial infections, but are more susceptible to autoimmune diseases.

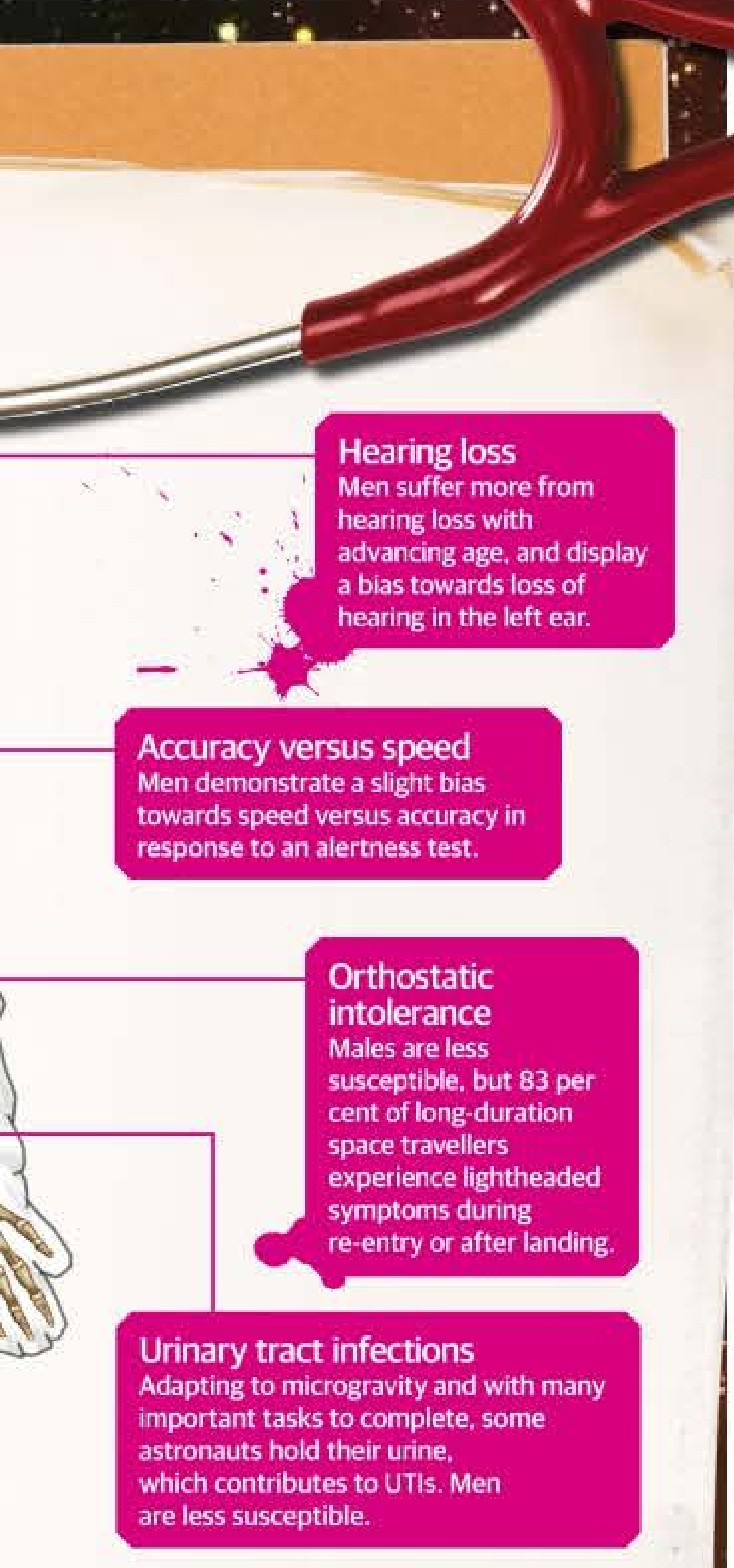
VIIP syndrome
During long spaceflights, over half of male astronauts experience VIIP symptoms.

Immune response
With a weaker immune response, men are less resistant to viral and bacterial infections.

Kidney stones
Kidney stones can range from tiny microscopic crystals to stones as large as walnuts, and cause excruciating pain. Calcium oxalate stones are more prevalent in men.

Muscle and bone loss
After six months in space, an astronaut's osteoporosis symptoms can be compared to those in elderly women on Earth, though there is large individual variability.

© NASA; Kevin McGivern;



Hearing loss
Men suffer more from hearing loss with advancing age, and display a bias towards loss of hearing in the left ear.

Accuracy versus speed
Men demonstrate a slight bias towards speed versus accuracy in response to an alertness test.

Orthostatic intolerance
Males are less susceptible, but 83 per cent of long-duration space travellers experience lightheaded symptoms during re-entry or after landing.

Urinary tract infections
Adapting to microgravity and with many important tasks to complete, some astronauts hold their urine, which contributes to UTIs. Men are less susceptible.

Counteracting the effect

Cosmic rays

Enhanced shielding would certainly help, so building Mars-bound spacecraft in space could be an option to allow well-shielded vehicles too heavy to lift off from Earth to be assembled. Meanwhile, cosmic-ray fighting drugs, preventive medical treatments, enhanced foods and special exercise regimes are promising to help the body repair damage.

If damage has already affected an astronaut's performance, intelligent systems could take over critical decision making – but hopefully not with the catastrophic outcome wrought by the sentient computer HAL 9000 in *2001: A Space Odyssey*.

Microgravity

Artificial gravity, as envisioned aboard Discovery One in the classic film *2001: A Space Odyssey*, might counteract the brain changes caused by microgravity. If this proves impossible though, astronauts could simply rehearse various actions in their mind (called mental imagery) which has been shown to improve sensorimotor performance, muscular force and preparation for the sudden absence of gravity after launch.

> "Even short-duration microgravity exposure or gravitational alterations induce changes in the brain"

NASA astronaut Dan Burbank during his six-day-a-week, two-and-a-half-hour exercise programme

I noticed that after bed rest there was crowding of brain tissue at the top of the brain."

Aiming to corroborate her finding, Roberts then studied the brain MRI scans of NASA astronauts before and after spaceflight - one set who had taken short missions on the Space Shuttle and another who had stayed longer on the ISS. "I had two neuroradiologists have a look at the MRI scans, but I didn't tell them which group of astronauts the scans came from," she says. Strikingly, the neuroradiologists confirmed Roberts' suspicions, concluding that there was an upward shift of the brain and expansion of tissue along the top of the brain in all astronauts on longer missions, just like in the bed-rest volunteers.

What this means is still not fully understood, but Roberts suspects that it may ultimately result in a decrease in the outflow of cerebrospinal fluid and blood from the head, which in turn leads to intercranial pressure. This intercranial pressure is believed to cause the VIIP symptoms experienced by some astronauts.

More worryingly, the crowding of tissue along the top of the brain may affect how an astronaut senses their environment and their ability to interact with it. This area, known as the central sulcus, is so critical that neurosurgeons operating in this part of the brain often perform surgery while the patient is awake to avoid injury. "Disturbances in the ability to carry out specific motor tasks have been found during spaceflight," says Roberts. Although it is not certain that tissue crowding is the reason for this, she warns that "any change to this region of the brain raises concerns".

Now, Roberts is collaborating with University of Florida investigator Professor Rachael Seidler to understand the effects of space on the brain. Seidler conducted the first brain MRI scans on astronauts in a 2016 study to look at regional changes of grey matter distribution, with some parallel findings to those of Roberts. Importantly though, Seidler's study captured how the brain expands in regions that process information and control movement of the legs, suggesting that the MRIs showed the brain learning the new skill of moving in microgravity. "Because of microgravity, the sensory information astronauts are getting from the limbs is greatly reduced, so we think this is the brain's way of turning up the gain of the system," she says.

The two investigators are pooling their knowledge on a NASA-sponsored bed-rest study to evaluate any change in the blood flow to the brain and brain structure that might occur during bed rest, with the added complication of carbon dioxide exposure. "Experiments on Earth have shown that people get headaches or have a little cognitive fogginess in that kind of environment," explains Seidler. Subjects have been exposed to an atmosphere that has lower levels of CO_2 than typical carbon dioxide exposure studies, but slightly higher levels than are typically found on Earth - similar to the atmosphere experienced by astronauts on the ISS. "The levels on the ISS are much lower, but astronauts report the same symptoms as people taking part in CO_2 exposure studies, so the question is: is there something about the combination of increased fluid in the brain with elevated CO_2 that magnifies the effects?" Says Seidler. Having just finished collecting data, results will be coming soon.

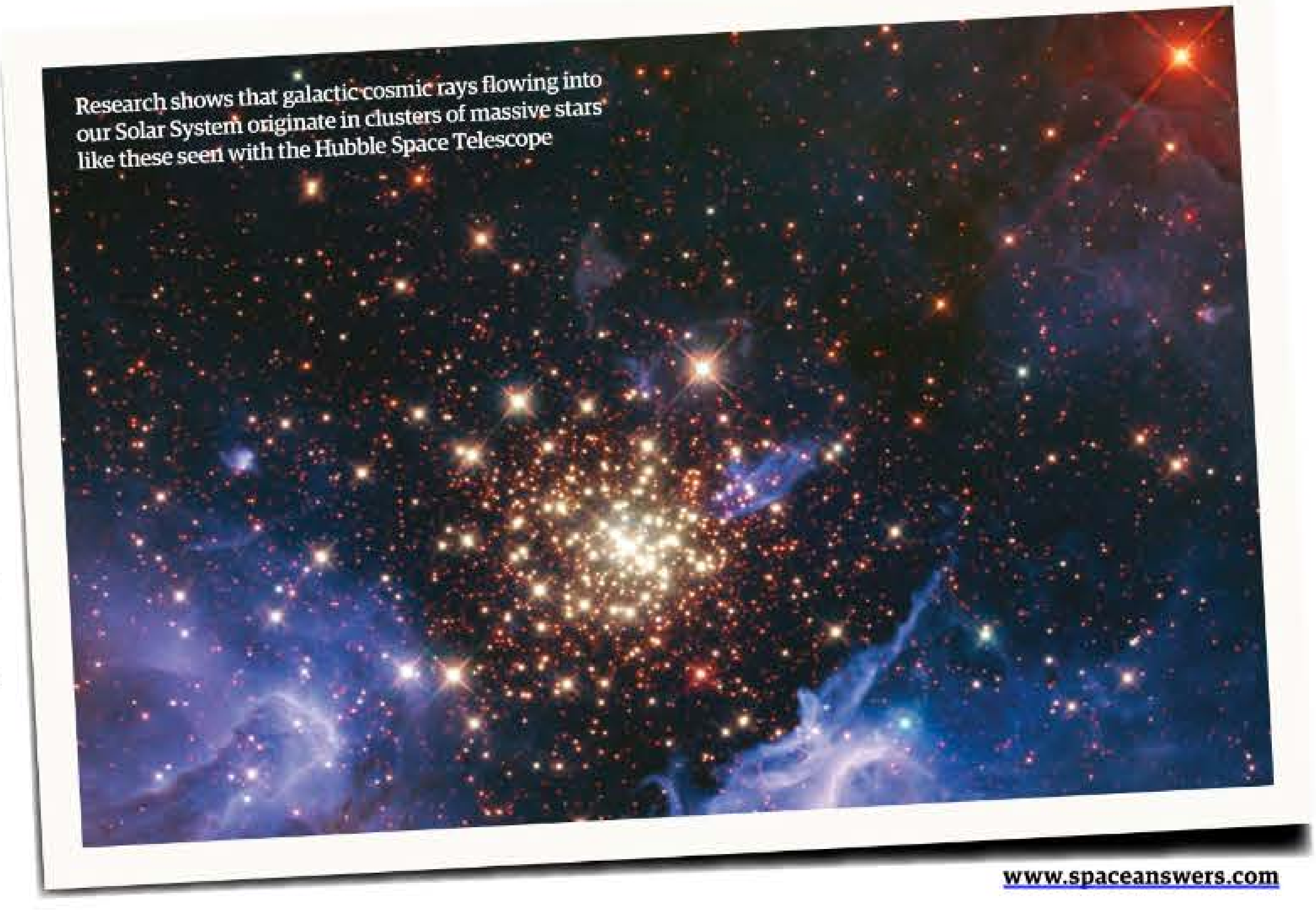
Progress in understanding how the brain is affected by microgravity is also being made on the other side of the Atlantic. Angelique Van Ombergen, from the University of Antwerp, Belgium, works with Belgian and Russian colleagues in a project led by Floris Wuyts to try to understand the physiological changes taking place during spaceflight. With a willing male cosmonaut who had spent 169 days on the ISS happy to have his brain analysed, they found that the brain's cortex reorganises itself to adapt to the challenges of a long-duration spaceflight. Noting less connectivity strength in certain brain areas, the team is looking to confirm if these changes cause temporary movement issues - like difficulties with walking, gait and posture - and balance problems - like dizziness, vertigo and nausea - astronauts experience when returning to Earth.

Taking a different tack, this year the team reported findings from a study in which volunteers had an MRI before and after a parabolic flight. Jokingly known as a 'vomit comet', parabolic flight involves an aircraft following a trajectory in which a steep climb precedes a 20-second levelling out period, during which the acceleration of the aircraft cancels out the acceleration of gravity - resembling zero gravity. A steep descent then takes the aircraft back to its initial altitude, ready to restart. Normally used by astronauts to prepare for the sudden absence of gravity after launch, in Van Ombergen's study 28 participants were loaded in an Airbus A-300 Zero G aircraft, and were then subjected to 31 parabolic flight manoeuvres over the course of approximately three hours.

Interestingly, although warning that there are some crucial differences between parabolic flight and spaceflight, Van Ombergen says the study shows that even short-duration microgravity exposure or gravitational alterations induce changes in a brain region specifically involved in multisensory integration and spatial tasks. In other words, this brain change led participants to experience symptoms of dizziness and disequilibrium similar to people here on Earth with a central vestibular disorder.

It is well known that space motion sickness and spatial disorientation is experienced by 60 to 80 per cent of astronaunts during the first couple of days in space, but understanding how and why it happens is

> "Disturbances in the ability to carry out specific motor tasks have been found during spaceflight" **Dr Donna Roberts**



Research shows that galactic cosmic rays flowing into our Solar System originate in clusters of massive stars like these seen with the Hubble Space Telescope

Chris Cassidy of NASA is too weak to walk shortly after he landed at the end of a five-and-a-half-month mission

© NASA

Symptoms

How can microgravity change you?

Blurred vision
Fluid not flowing out of the brain increases pressure to the back of the eye, flattening the eyeball, pushing the retina forward and inflaming the optic nerve.

Weak motor and multi-tasking skills
Crowding of tissue in the frontal and parietal lobes may be behind poorer motor task performance during spaceflight, particularly while astronauts simultaneously engage in secondary cognitive tasks.

Movement and balance back on Earth
Reduced connectivity between the motor cortex and cerebellum could be causing the temporary movement and balance problems astronauts experience upon return to Earth.

Space motion sickness
This syndrome may come from changes to a region of the brain that processes balance, body position and visual input, and how we perceive what is up and down.

Death by cosmic rays?
Damaging delicate neuronal structure, cosmic rays have the potential to compromise an astronaut's ability to make critical decisions on a deep-space mission, with calamitous consequences.

Death by CO_2?
Similar to the effects of cosmic rays, some reports show negative consequences in terms of sleep, cognition and psychomotor performance from elevated carbon dioxide levels.

> "Space tourism and long stays on the ISS are not the only trips space administrations need to prepare for"

important, particularly when large groups of untrained tourists begin launching into space. Just as vigorous exercise combats muscle wastage in astronauts, Van Ombergen's work is a step towards developing countermeasures to help astronauts and space tourists cope with gravity transitions too.

Of course, space tourism and long stays on the ISS are not the only trips space administrations need to prepare for. With expeditions and even eventual colonisation of the Moon and Mars planned for the coming decades, astronauts' bodies will have to contend with much more than the effects of microgravity. This is because, for the first time, they will be dealing with long-term exposure to cosmic radiation. "Radiation on Earth is what we call sparsely ionising, while galactic cosmic rays are densely ionising," explains Charles Limoli from the University of California, Irvine. "When these densely ionising rays travel through the body, they leave behind a track of damage that the body's cells find very difficult to repair."

Consisting of anything from hydrogen nuclei all the way up on the Periodic Table to lead, galactic cosmic rays consist of atoms stripped of their electrons speeding through the galaxy at near the speed of light. When they pass through the body they cause molecules in living tissue to break apart. "Then, travelling perpendicular from the track are what we call delta rays," adds Limoli. "These are more sparsely ionising radiation tracks that can emanate away from the primary track - imagine a one centimetre cylinder of potential cellular damage for every heavy particle passing through your body."

"Even on the ISS, astronauts report seeing flashes of light, which are pieces of galactic cosmic radiation that are passing though and stimulating the optic nerve," reveals Thomas Williams, a scientist at NASA's directorate for Human Health & Performance.

The effects of these rays are unclear, but Limoli is conducting rodent experiments here on Earth to find out how they might affect the brain, and his results paint a bleak picture. After being exposed to low dose of highly ionising radiation, rodents became far less able to perform behavioural tasks, such as being able to tell a new object from a familiar one. Most worryingly, the rodents did not recover - even after a year. Analysis of the rodent's brains highlighted the problem. The radiation caused persistent neuroinflammation, lasting for more than six months and irrevocably damaged the integrity of the rodent's neural circuits.

On a Mars mission, this kind of damage could impair memory, learning, planning, focus and multi-tasking skills, all while simultaneously increasing the fear response and anxiety. Considering Mars astronauts will undoubtedly be required to make mission-critical decisions quickly, none of this bodes well for future explorations.

Because of this, work is already underway to counteract the potential damage from cosmic rays. "Biological countermeasures targeted against oxidative and inflammatory pathways, advanced shielding methodologies implementing new materials and even utilising specially designed helmets to protect the brain are all being pursued," remarks Limoli, who is himself deeply involved in designing top-secret cosmic-ray-fighting drugs.

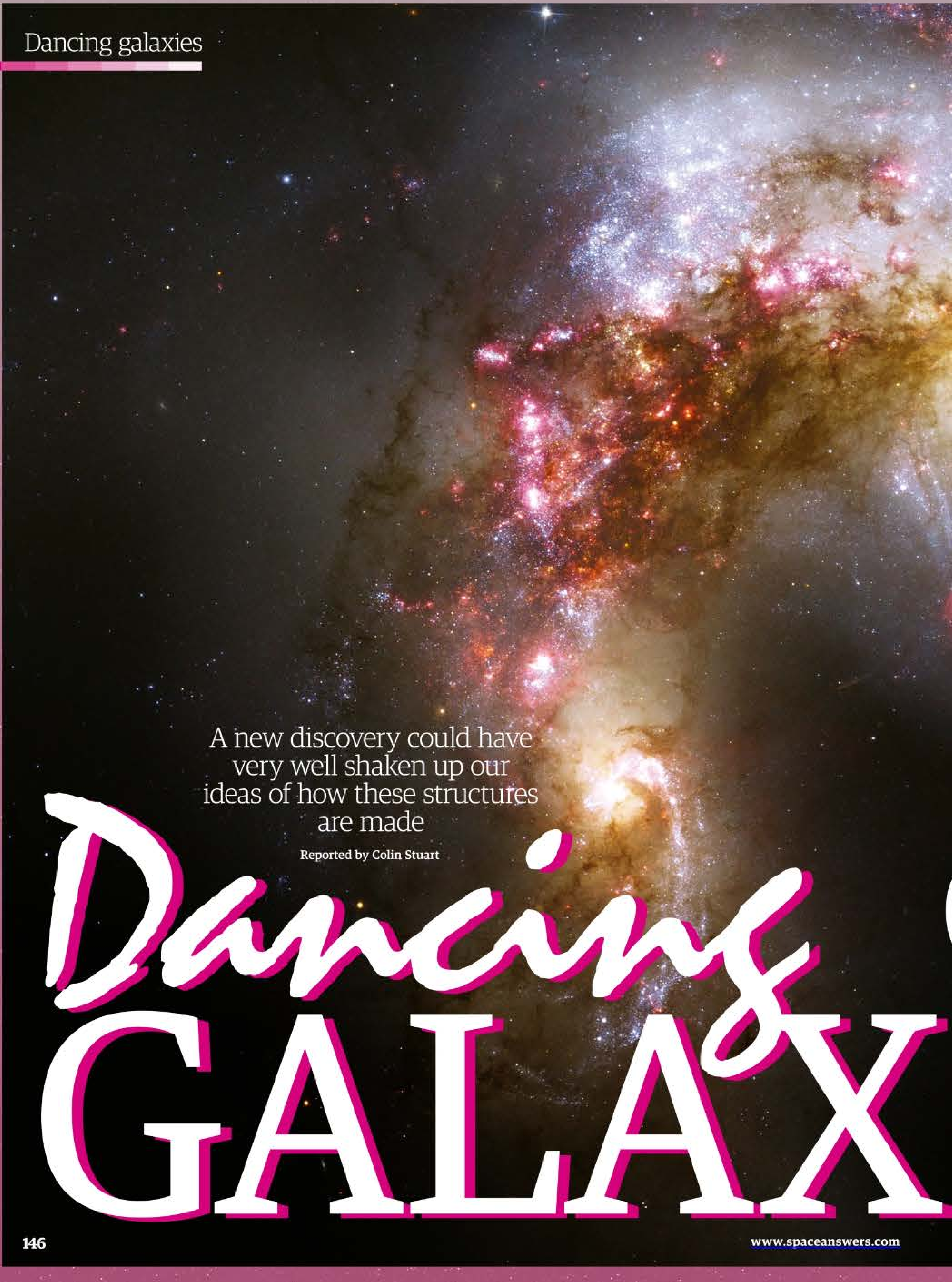
"One area we're looking at is preventive medical treatment based on really interesting studies on helping to prevent the damage from radiation treatment back here on Earth," adds Williams. "Bionutrients is another fascinating area - how do we harness what nature presents to us to help protect our crews against the effects of radiation?"

Limoli concludes: "We need to protect these people, not only for a mission to Mars, but for future missions over the coming millennia."

Dancing GALAX

A new discovery could have very well shaken up our ideas of how these structures are made

Reported by Colin Stuart



Space can be a bit of a mess. Take the moons of Jupiter, for example. Its four largest satellites - Ganymede, Callisto, Io and Europa - all orbit in the same direction around the planet and in the same flat disc. Yet the remaining 65 moons spin around Jupiter at all sorts of random angles and in different directions. That's because the big moons are thought to have formed together with Jupiter. By contrast, the smaller ones were probably passing asteroids or comets caught up in the web of the giant planet's gravity. For the big moons there was some underlying order. The rest have been randomly dumped there over time.

To astronomers studying galaxies, the picture is very similar. These vast collections of hundreds of billions of stars form when smaller objects come together under gravity. Once assembled, they continue to collect material in the form of dwarf galaxies - runts of the litter drawn in by the gravity. By all rights these diminutive orbiters should be trundling around the galaxy at all sorts of random angles depending on the exact trajectory they initially came in from in the first place - just like the smaller moons of Jupiter. "That's what you get when you try and build galaxies in computers," says Oliver Müller, from the University of Basel. These highly detailed computer simulations take into account dark matter. Although it hasn't been detected directly, astronomers think this invisible substance binds cosmic structures together.

Except, the dwarf satellites of the two galaxies we can see best - our own Milky Way and our nearest neighbour, Andromeda - don't appear to play by those rules. They all appear to orbit in a similar plane. It's as if they have been placed there carefully, rather than haphazardly assembled over time. To explain this discrepancy, astronomers have previously dismissed the Milky Way and Andromeda as oddballs that aren't representative of the wider universe, but a new discovery regarding the galaxy Centaurus A is causing a stir. According to a recent study led by Müller, 14 out of 16 of its dwarf galaxies orbit in the same plane. Could it mean our ideas about dark matter are wrong?

Centaurus A is a particularly well-studied galaxy because it has always stood out from the crowd. It was discovered in 1826 by Scottish astronomer James Dunlop while observing the night sky from

Müller hopes future observations with the VLT will help settle the debate

© ESO/M. Kornmesser

Australia. The fifth-brightest galaxy in the sky, it is also one of the nearest active galaxies to us. At its heart is a black hole tipping the scales at 55 million-times the mass of the Sun. The supermassive black hole at the centre of own Milky Way is tiny by comparison at just four million solar masses. Centaurus A's behemoth is gorging on material so vociferously that it creates an intense beam of X-rays and radio waves roaring away from its centre that can be seen through a professional telescope. The galaxy is also undergoing an exceptionally high rate of star formation, probably due to the fact it stemmed from the collision of an elliptical galaxy with a smaller spiral galaxy.

Müller's recent finding regarding its unusually aligned dwarf galaxies is not the first time someone has spotted something odd in the environs around Centaurus A. In 2015, astronomers discovered the region is home to dark globular clusters, dense groups of stars that appear to have much more mass than their constituent stars alone. Perhaps they play host to more dark matter, or maybe they boast a higher population of black holes. Centaurus A was already challenging what we know about galaxy formation and dark matter - Müller's result merely underlines its weirdness.

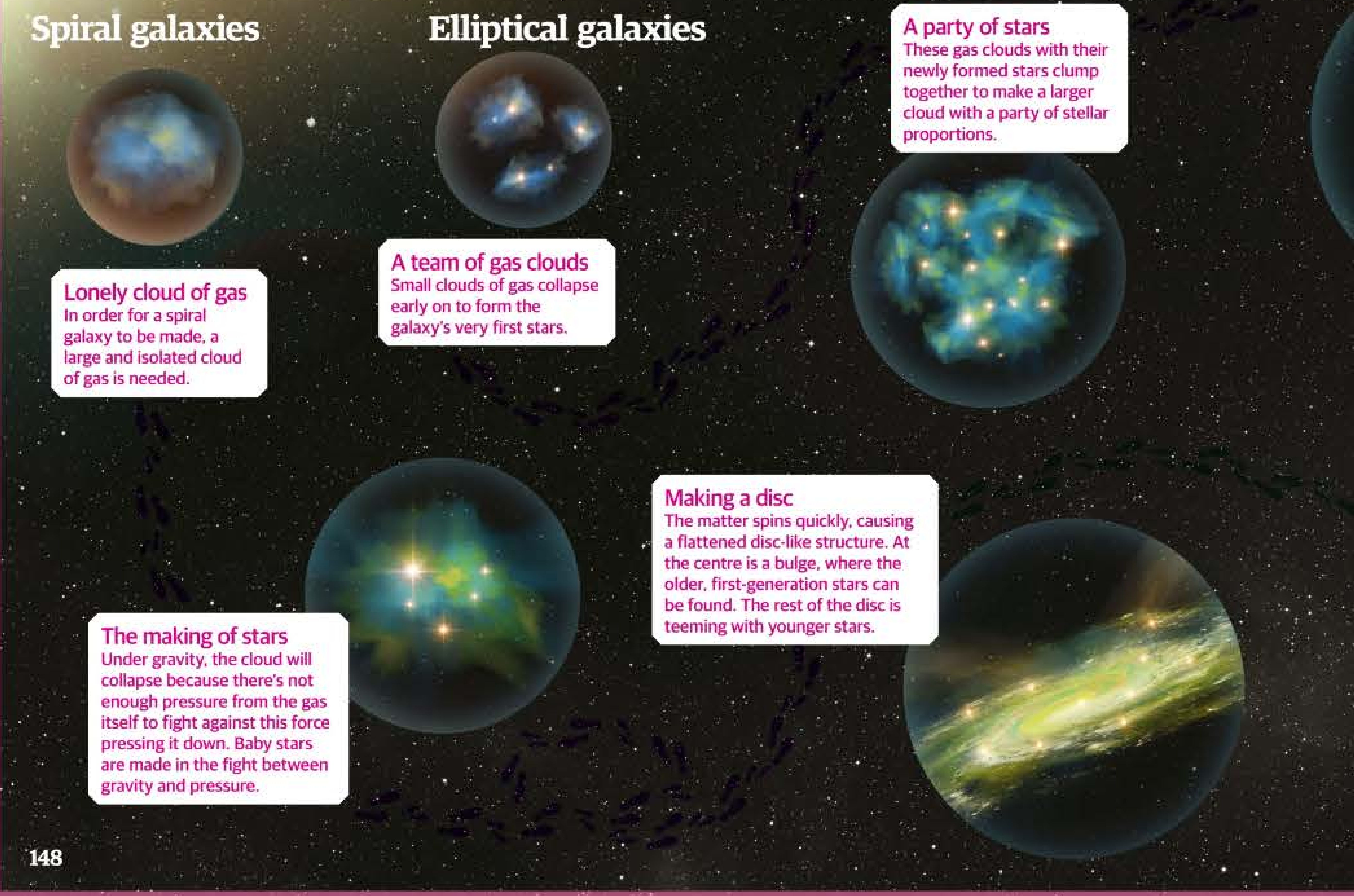
To study the movement of Centaurus A's dwarf galaxies, Müller used one of the most powerful tools in an astronomer's armoury: redshift and blueshift measurements. We've all heard the effect when a police car screeches by with its siren blasting. When it is moving towards you it is high-pitched, but its pitch drops as it speeds away. That's because it's dragging the sound waves out as it moves further

Scottish astronomer James Dunlop discovered Centaurus A in 1826 from Australia

> "It's a hard thing to tell when you're observing a galaxy from one angle - as we have to" **Karen Masters**

How we think galaxies are made

Depending on their type - whether they're a spiral or elliptical - these structures follow different evolutionary paths



Spiral galaxies

Elliptical galaxies

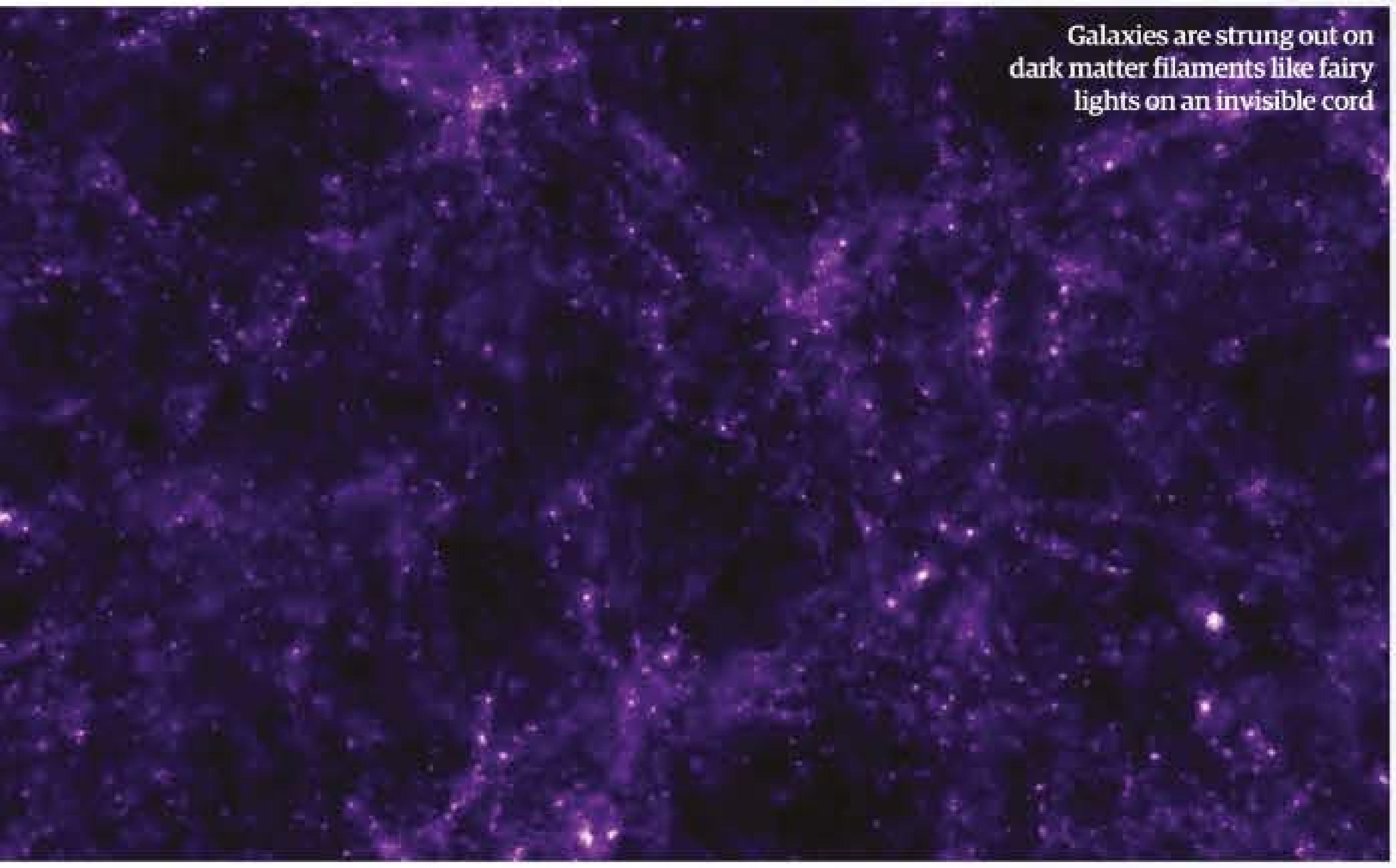
Lonely cloud of gas
In order for a spiral galaxy to be made, a large and isolated cloud of gas is needed.

The making of stars
Under gravity, the cloud will collapse because there's not enough pressure from the gas itself to fight against this force pressing it down. Baby stars are made in the fight between gravity and pressure.

A team of gas clouds
Small clouds of gas collapse early on to form the galaxy's very first stars.

A party of stars
These gas clouds with their newly formed stars clump together to make a larger cloud with a party of stellar proportions.

Making a disc
The matter spins quickly, causing a flattened disc-like structure. At the centre is a bulge, where the older, first-generation stars can be found. The rest of the disc is teeming with younger stars.

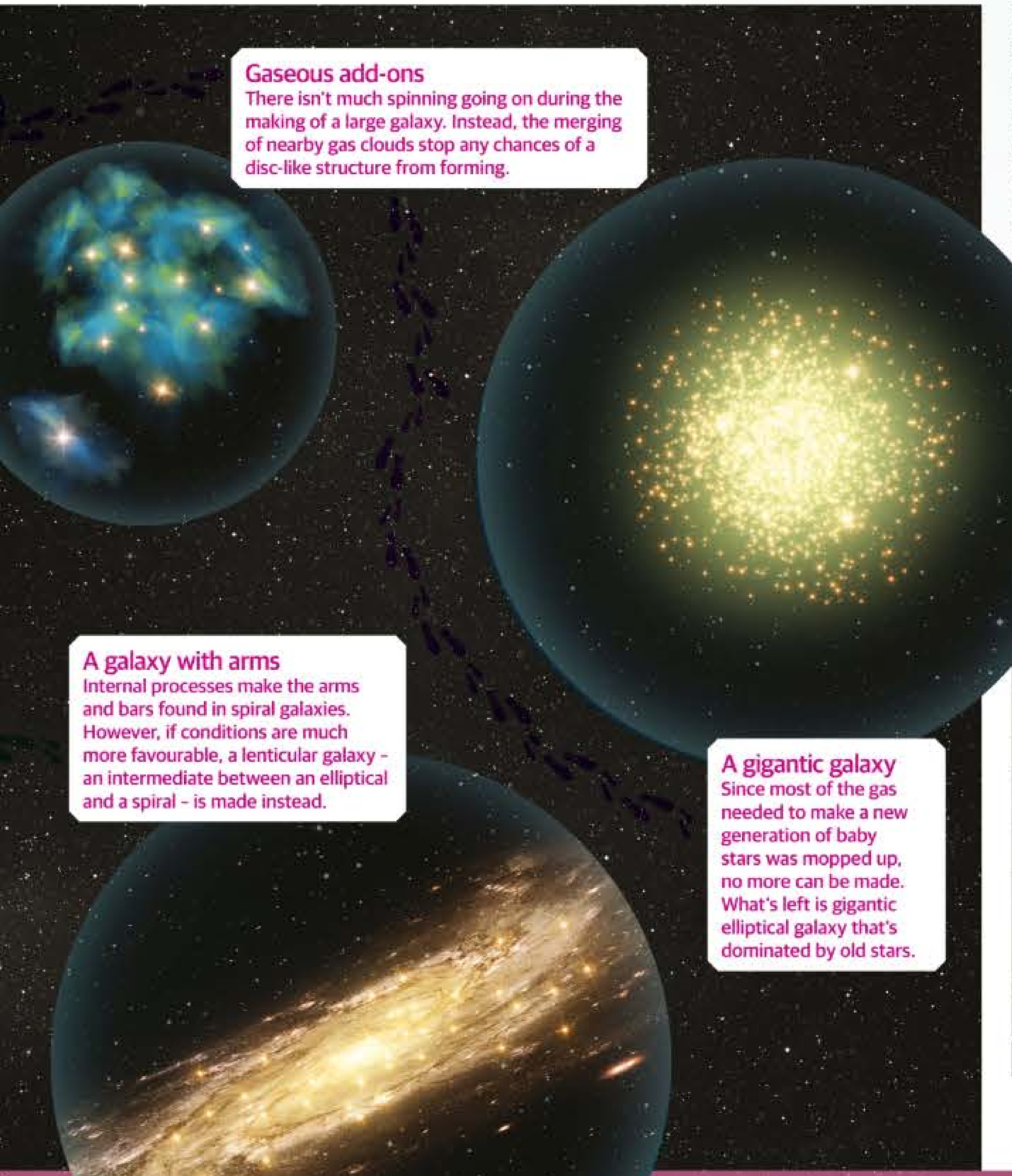


Galaxies are strung out on dark matter filaments like fairy lights on an invisible cord

from you. Light is a wave, too, and moving light sources affect the frequency of its waves. Except it isn't the pitch that changes, but the colour. A light source moving towards you will appear bluer; a receding light seems redder. In practice, the shifts are so small that astronomer's need to look closely at an object's spectrum. Break its light up using a spectrometer - a fancy prism - and you get a spectrum of rainbow colours interwoven with a series of black lines representing missing colours where different chemical elements in the galaxy have swallowed that particular frequency. It is these 'absorption lines' that appear shifted towards the blue or red ends of the spectrum depending on the movement of the dwarf galaxy. The more they are shifted, the faster the dwarfs are moving.

Müller measured the redshift and blueshift of Centaurus A's dwarf galaxies and mapped out their orbital paths to within an accuracy of five per cent, finding almost all of them in the same plane - much like how Jupiter's four largest moons all orbit the planet in a flat disc. How did they end up this way? It's worth saying it could just be a deceptive fluke. Centaurus A has more dwarf galaxies that have yet to be studied. Maybe Müller just happened upon the ones that share an alignment and the rest will turn out not to follow suit. Although he says the chances of that are just 0.5 per cent, if he's right he says it would challenge the status quo that argues such an alignment is hard to achieve in a universe dominated by dark matter. Although some dark matter computer simulations do generate dwarf galaxies in a temporary alignment, Müller says that they are not stable over time and they almost always go back to be being mis-aligned.

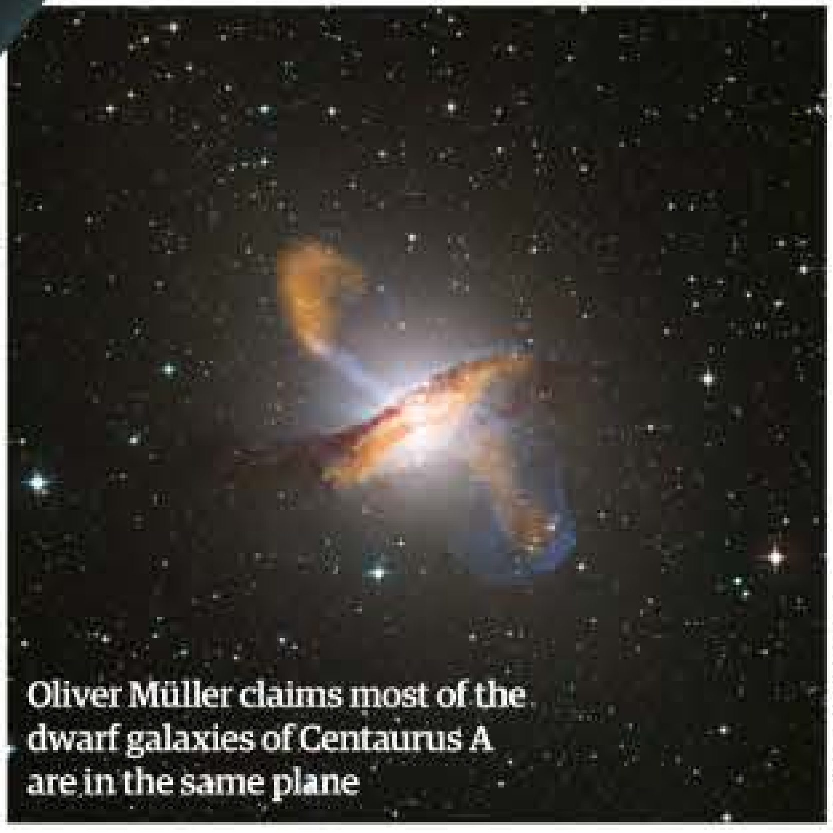
Karen Masters, a galaxy expert from Haverford College in Pennsylvania, isn't so sure. "It's a hard thing to tell when you're observing a galaxy from one angle - as we have to - because we live where we live and we don't have a different angle to look from," she says. Masters points to other computer simulations that looked at how often dwarf galaxies may look like they are co-rotating around their host, but in fact that was an illusion caused by our viewing angle. "It's not that unusual to see apparent planes of satellites around galaxies," she says.



Gaseous add-ons
There isn't much spinning going on during the making of a large galaxy. Instead, the merging of nearby gas clouds stop any chances of a disc-like structure from forming.

A galaxy with arms
Internal processes make the arms and bars found in spiral galaxies. However, if conditions are much more favourable, a lenticular galaxy - an intermediate between an elliptical and a spiral - is made instead.

A gigantic galaxy
Since most of the gas needed to make a new generation of baby stars was mopped up, no more can be made. What's left is gigantic elliptical galaxy that's dominated by old stars.



Oliver Müller claims most of the dwarf galaxies of Centaurus A are in the same plane

© ESO; Tobias Roetsch

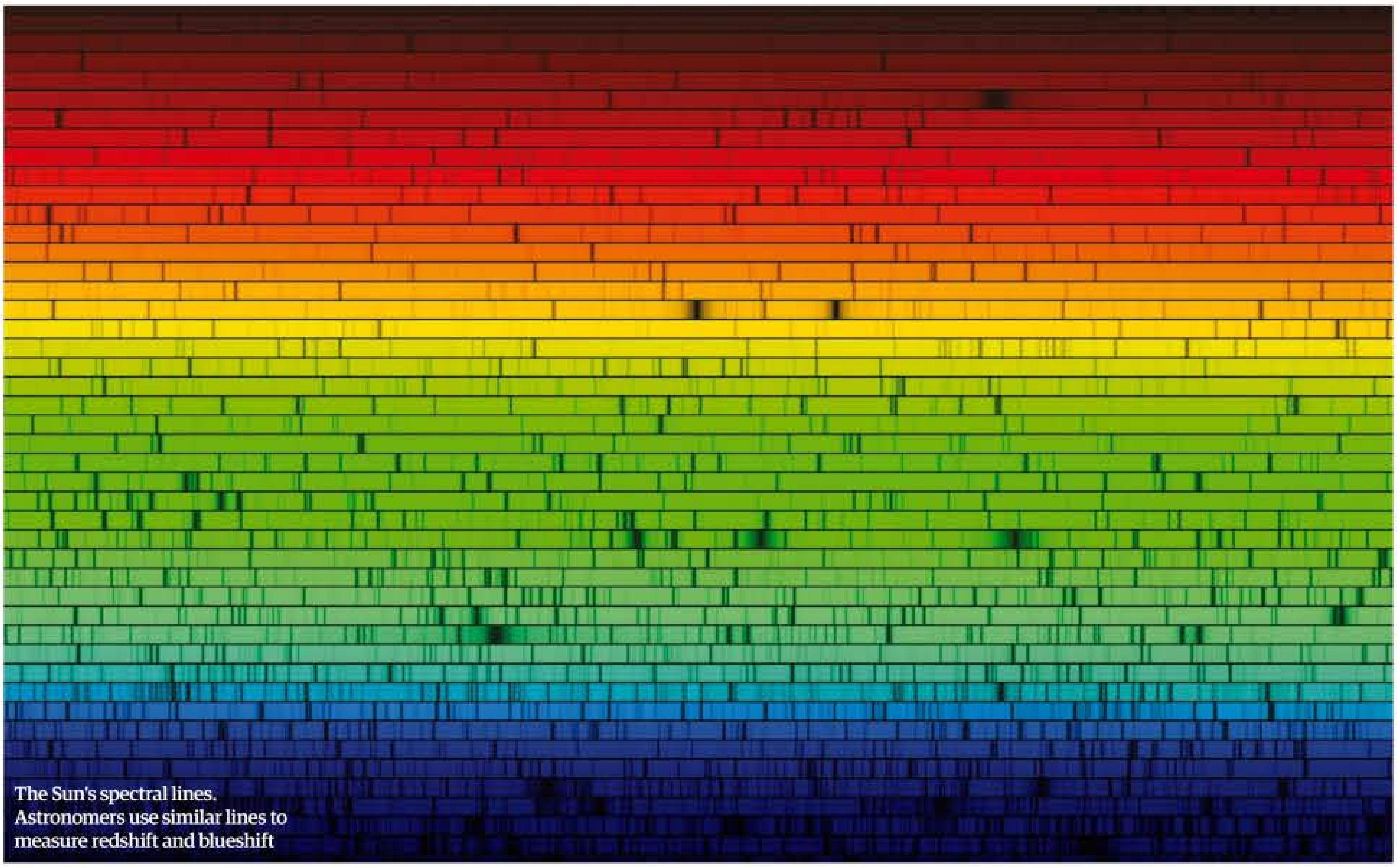
Jupiter's four largest moons share the same plane and direction around the planet

Let's say the alignment is real and the dwarf galaxies really are co-rotating in a plane around Centaurus A. Does that really challenge our ideas about dark matter? Perhaps if you only consider the dark matter and gravity of Centaurus A alone, but there is more to intergalactic space than meets the eye. Galaxies are strung out on vast chains of dark matter known as filaments, like fairy lights dotted along an invisible cord. Back in 2015, a team of astronomers led by Noam Libeskind from the Leibniz Institute for Astrophysics in Potsdam, Germany, mapped out the cosmic web of dark matter in the local universe. They were able to do this by tracing out the trajectories of objects moving through the area under the influence of dark matter's gravitational pull. In doing so they discovered a vast filament of dark matter stretching over fifty million light years from the Virgo Cluster of galaxies across our Local Group. Crucially, four out of the five dwarf galaxy planes they studied were aligned with this filament.

Masters believes that's what's really going on with Centaurus A. "The idea that galaxies should come in from random directions is not a good assumption," she says. "It is based on simulations that were done more than ten years ago." Think of the filaments as rivers of dark matter. Dwarf galaxies get swept up in the current. When you consider this picture of dark matter flowing along filaments between galaxies and galaxy clusters, Masters says dwarfs will end up settling in a preferential direction around galaxies in the direction of the flow. "Why the people who published this don't recognise this I don't know," she says. As far as she's concerned, this result doesn't pose a challenge to our ideas about dark matter – it confirms them when you consider the effect of the shadowy substance on a bigger scale.

Masters isn't the only one not buying Müller's result. Rachael Beaton, from the Carnegie Observatories in California, thinks he has been too optimistic about the accuracy of his measurements. Measuring the redshift and blueshift precisely relies on picking out bright individual stars within the dwarf galaxies. Astronomers have calculated the distance to Centaurus A at between 10 and 16 million light years. From that distance bright stars are in short supply, and Beaton believes that an accuracy of ten per cent is more realistic. If that's the case, there is enough wiggle room for the dwarfs to appear to orbit in the same plane, even though in reality they don't. That would mean there's no challenge to our prevailing ideas about dark matter and its role in galaxy formation. It would, however, shift the emphasis from looking at galaxies as islands in space cut off from each other to seeing them as interconnected in a tangled web of dark matter filaments.

Before astrophysicists throw out Müller's ideas completely, he is planning to examine more of the dwarf galaxies around Centaurus A to firm up the picture. He has already had a proposal accepted to use the Very Large Telescope (VLT) in Chile for such a purpose, and those observations should be made later this year. It is equipped with some of the best spectroscopes in the world, meaning Müller should be able to accurately pin down their blueshifts and redshifts. It remains to be seen if this oddball galaxy will lead to a revolution in our understanding of the universe.



The Sun's spectral lines. Astronomers use similar lines to measure redshift and blueshift

© NASA/JPL; Nigel Sharp & National Science Foundation; Tobias Roetsch

The dance of the galaxies

Synchronised galaxies

Single plane
Centaurus A's satellites have been found to orbit in a single plane, rather than randomly, while it rotates coherently. Dwarfs on one side are receding whilst the others are moving towards us.

Synchronised galaxies
The dwarf galaxies in orbit around Centaurus A have been discovered to orbit their host in a more uniform path.

Bucking the trend
According to our current theories of the universe, fewer than one per cent of satellite galaxies exhibit similiar behaviour.

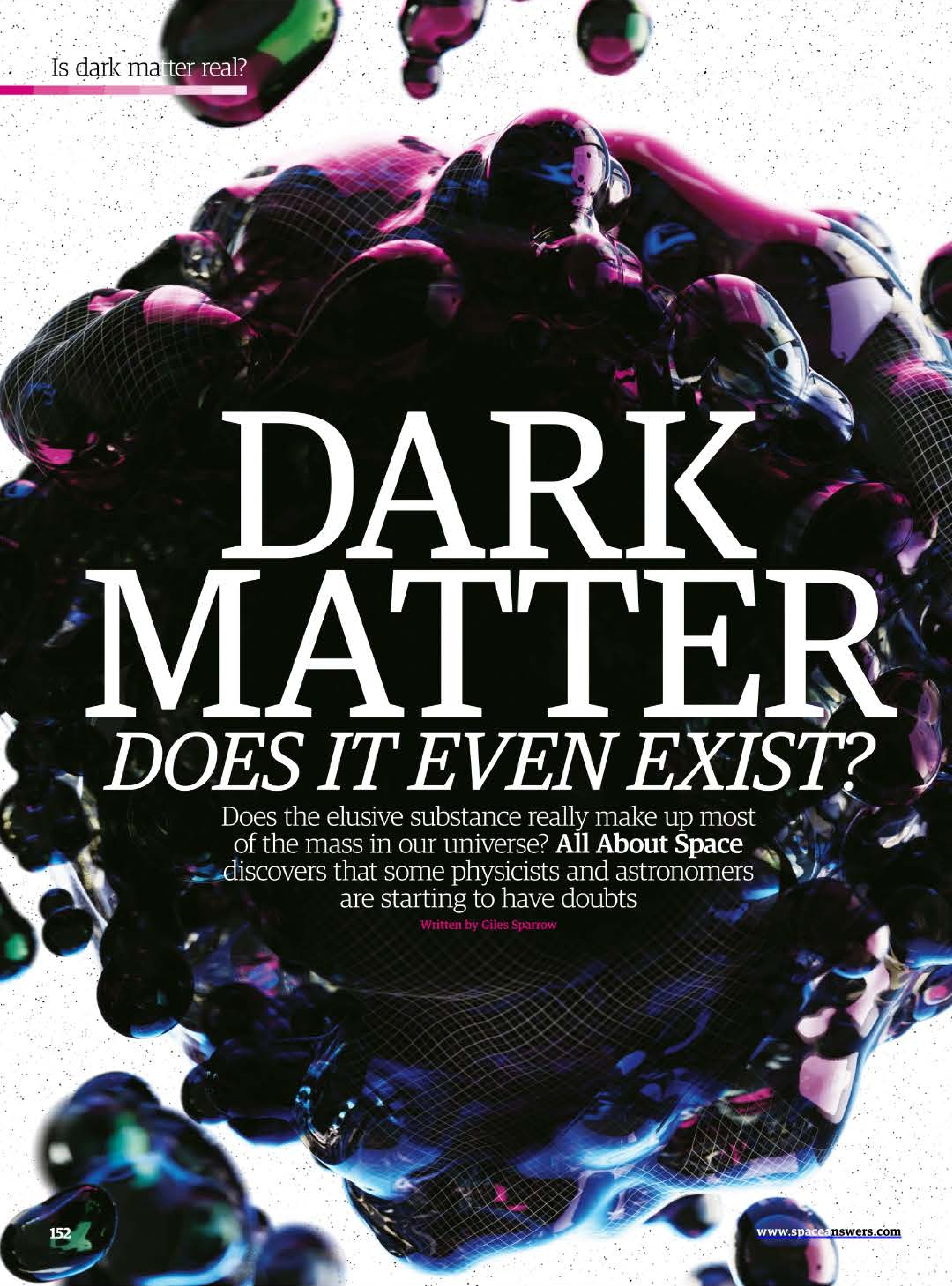
'Standard' galaxies

Random arrangement
According to what we know to be the 'cosmological ingredients' such as dark matter suggest that small dwarf galaxies should orbit in random positions and directions around their parent galaxy.

Andromeda & the Milky Way
Our galaxy and neighbouring spiral Andromeda have a mixture of randomly - and coherently - orbiting satellite galaxies.

> "The idea that galaxies should come in from random directions is not a good assumption"
> **Karen Masters**

Are our models wrong?
Most of the galaxies that we see today fit in with our models of evolution and cosmology, however, the small per cent of satellite galaxies we observe have left us questioning our theories.



DARK MATTER

DOES IT EVEN EXIST?

Does the elusive substance really make up most of the mass in our universe? **All About Space** discovers that some physicists and astronomers are starting to have doubts

Written by Giles Sparrow

For almost a century, astronomers have strongly believed that our universe is dominated by something we cannot see - a mysterious type of matter that neither emits nor absorbs light and other forms of electromagnetic radiation, and which reveals itself only through the influence of its gravity on objects we can directly observe. This 'dark matter' is thought to vastly outweigh the 'normal matter' that emits and interacts with light - it makes galaxies and larger cosmic objects behave as if they have, on average, about six-times the mass suggested by their visible stars, gas and dust. And yet, decades of attempts to directly detect this elusive matter

The speedy motion of stars in the outer reaches of spiral galaxies is strong evidence that something is wrong with our simplest models of the universe

> "The stars were moving faster than predicted by Newtonian gravity"
> **Margot Brouwer**

have unfortunately failed to produce any concrete evidence of their existence.

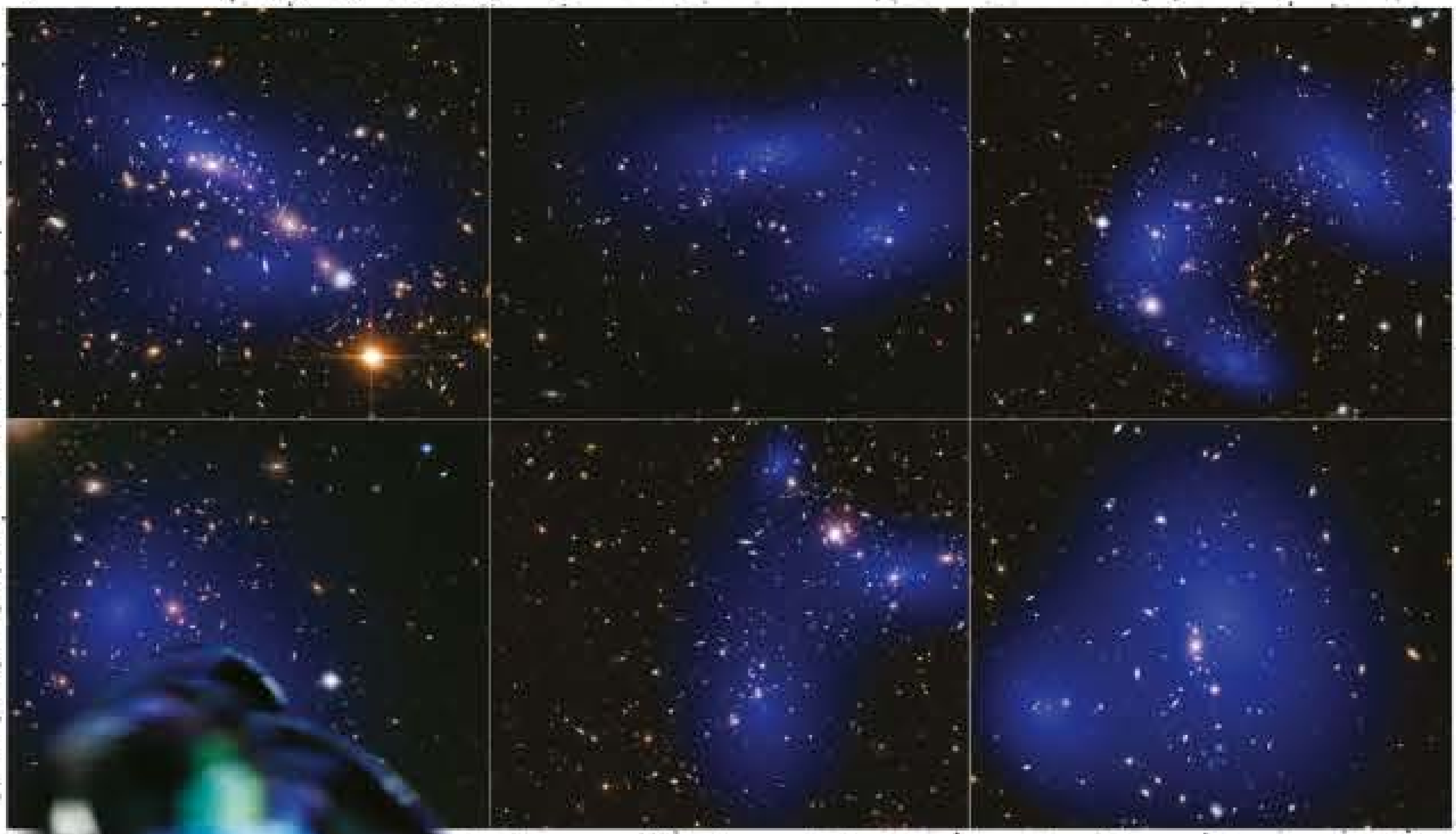
So is the 'dark matter paradigm' an accurate way of looking at our universe? Support for alternative theories, which instead rewrite long-standing laws of physics, is growing - and a recent astronomical study has offered the first observational evidence that one of these rebel theories is a remarkably good match for reality. Is 'dark matter' dead?

"The story started decades ago," explains Margot Brouwer of the University of Leiden, whose recent research has helped fuel the debate. "In the early 1930s, Dutch astronomer Jan Oort was studying how fast the stars in our Milky Way galaxy were moving. When he compared that to calculations based on Newton's laws of gravity, he found that they weren't moving in the way he expected - they're actually moving too fast."

Isaac Newton's laws of motion and gravity, published in 1687, describe how objects move under the influence of forces, including gravity. One of their most important consequences is that the speed of a small object orbiting a more massive one is related to both the distance between them, and the mass at the centre. The heavier the central mass, the faster the orbiting object must move at a given distance, so faster orbits for stars in the outer reaches of the galaxy implied more mass in the centre. The only problem was that the measurable amount of stars, gas and dust in the galactic core was only a small fraction of that required to produce such orbits.

"Later, lots of other scientists started to see the same thing," continues Brouwer. "In 1933, Swiss astronomer Fritz Zwicky was studying the speed of galaxies moving in large clusters, and he found they were also moving too fast. And then, in the 1970s, US astronomer Vera Rubin measured how fast galaxies were rotating around their centre, and she also found that the stars were moving faster than predicted by Newtonian gravity."

Rubin's work on what became known as the 'galaxy rotation problem' finally convinced most astronomers to take the issue seriously. Most agreed that the unexpected orbits really were due to the gravity of undetected matter (which Zwicky had named 'dark matter' as early as 1933). "If you look at the entire universe," explains Brouwer, "there has to be about five times as much of this 'dark matter' as



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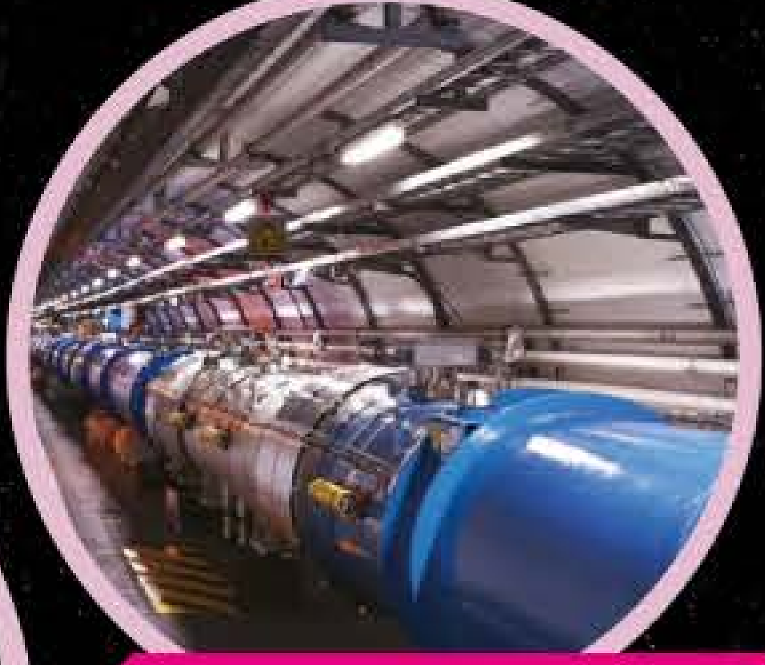
Colliding galaxy clusters are a big challenge for MOND - lensing seems to show their mass in different areas from their visible galaxies

The problem with dark matter

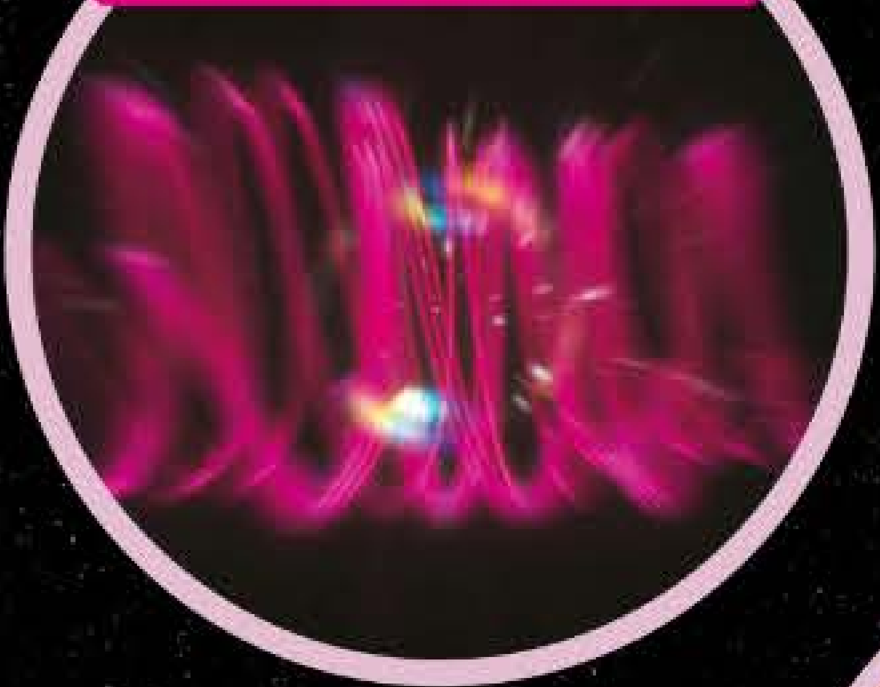
If we can't prove it's there, how do we know it exists?

Dark matter isn't 'normal'
Even when the mass of cold interstellar gas and dust, and compact, dark bodies such as the burnt-out cores of stars are taken into account, there's only enough normal matter to account for 1/6th of large-scale gravity.

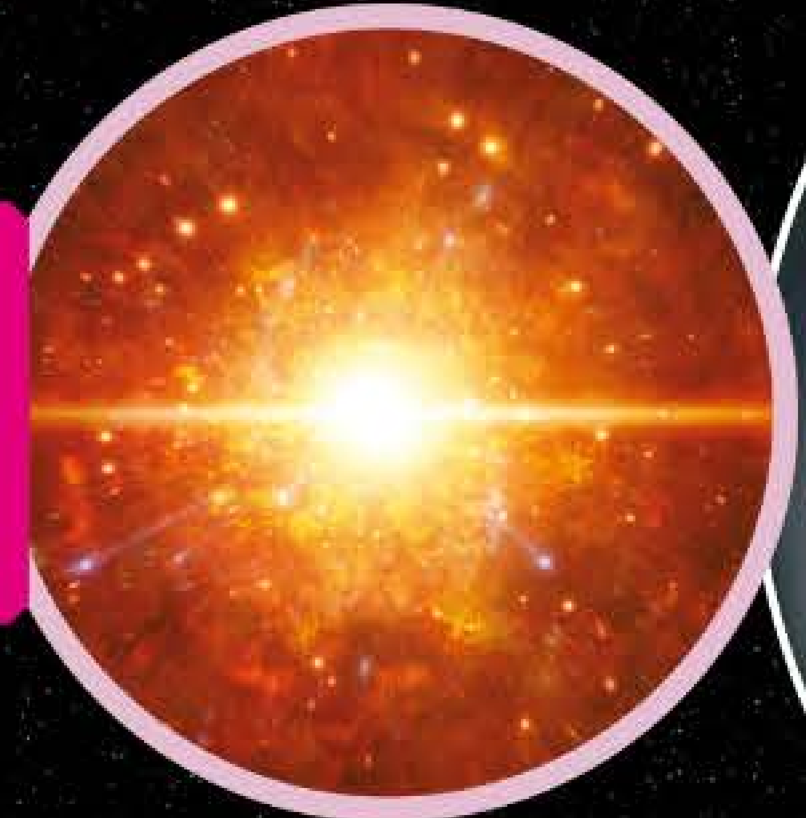


Why haven't we detected it?
If the universe is really dominated by strange particles that carry mass but don't interact with light, then why haven't underground particle detectors found any trace of them?

Why haven't we created it?
If dark matter is so abundant, why haven't experiments in particle accelerators, which specifically aim to create new subatomic particles, generated anything that looks like a dark matter particle?



Why are rotation curves so uniform?
A 2016 study comparing the rotation speeds of galaxies to the mass of their visible matter appeared to show a strong link that's hard to explain if the proportion of dark matter varies from one galaxy to the next.



Troubles with the Big Bang
Even if we could find another way of explaining, we would still need something like dark matter to explain the balance of mass and energy created in the Big Bang, and the way that gravity rapidly took control of the early universe.

© NASA; ESA; Sergio Valle Duarte; Maximilien Brice; Tobias Roetsch

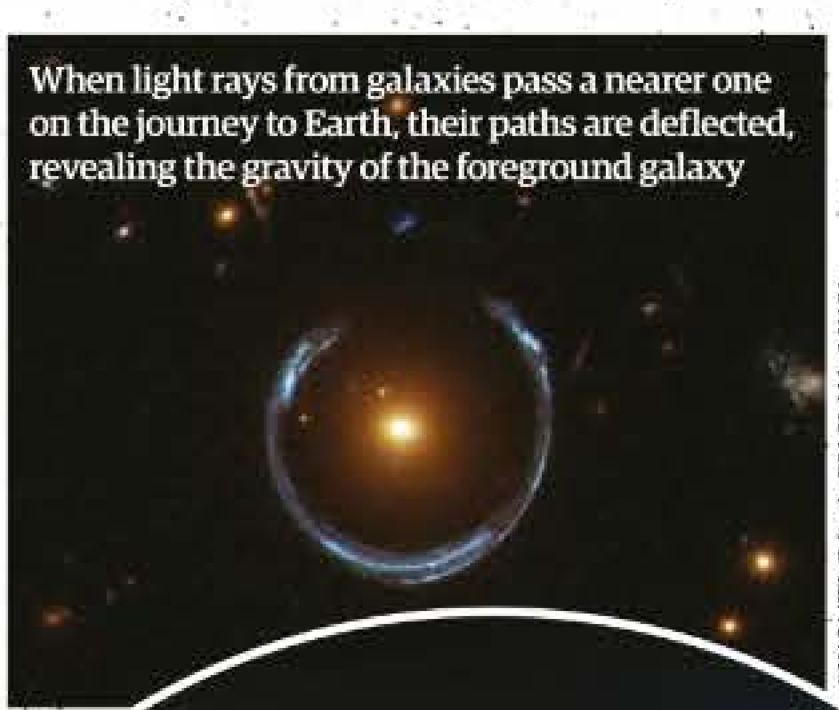
> "Of course there's still a hope that one day they'll track down dark matter particles"
> **Margot Brouwer**

the normal matter we can see, in order to make our calculations work using the framework of Newton and Einstein's gravity."

But what exactly was this matter? Many astronomers hoped it would turn out to be unseen normal matter – compact objects such as rogue planets and burnt-out stellar cores that could hold a lot of mass while rarely interfering with the light from other objects. But prolonged searches in and around our own galaxy found very few of these objects, and instead, most scientists reluctantly concluded that dark matter must be something very strange indeed – vast clouds of particles that permeate the universe but are somehow immune from all interactions with light.

The search for dark matter particles has continued for decades, but so far no suitable candidate has been directly detected. Astronomers have found supporting evidence for the influence of particle dark matter in collisions between galaxy clusters, and even the formation of large-scale cosmic structure in the early universe, but the particles themselves remain elusive.

Even as early as the 1970s, however, there was a minority view that missing forms of matter were not the only answer to the galaxy rotation problem.



When light rays from galaxies pass a nearer one on the journey to Earth, their paths are deflected, revealing the gravity of the foreground galaxy

©NASA/JPL-Caltech; ESA/Hubble & NASA

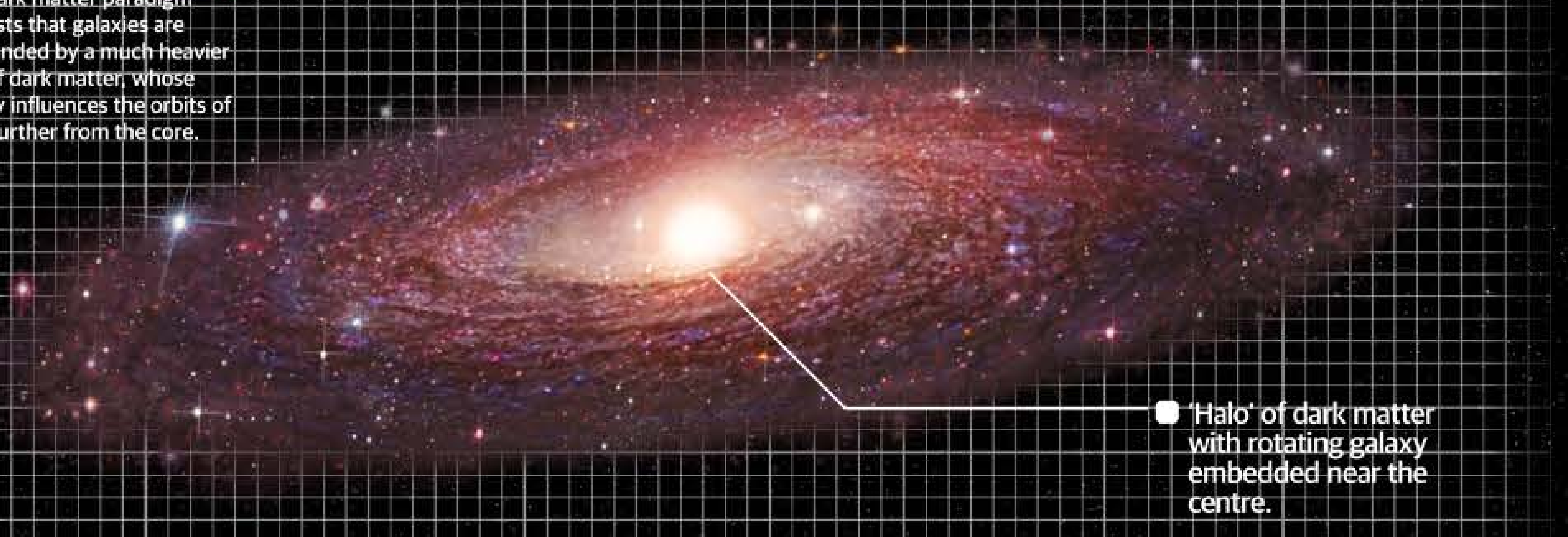
Could dark matter be explained by small, dense objects in the halos of galaxies? According to studies of the Milky Way, there just isn't enough of these objects to make a difference

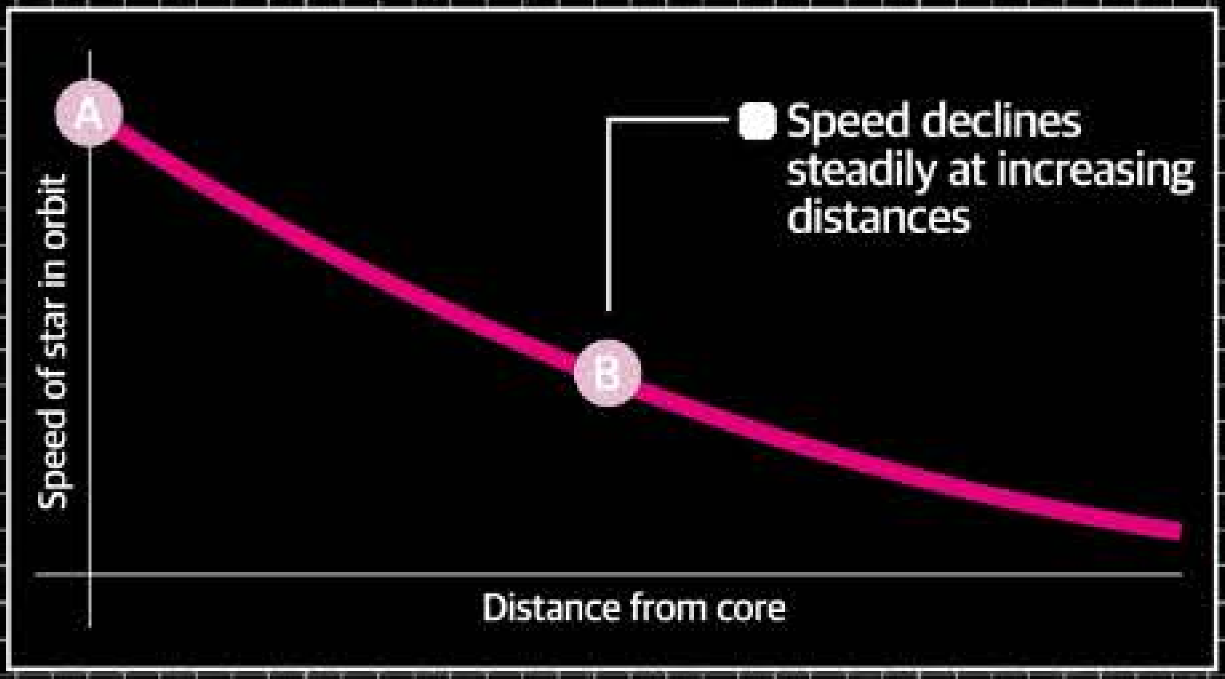
Dark matter replacement: MOND

MOND and dark matter both aim to explain a key pattern identified by Vera Rubin in the 1970s – the 'flat' rotation curves in the outer reaches of galaxies

1. Dark matter solution

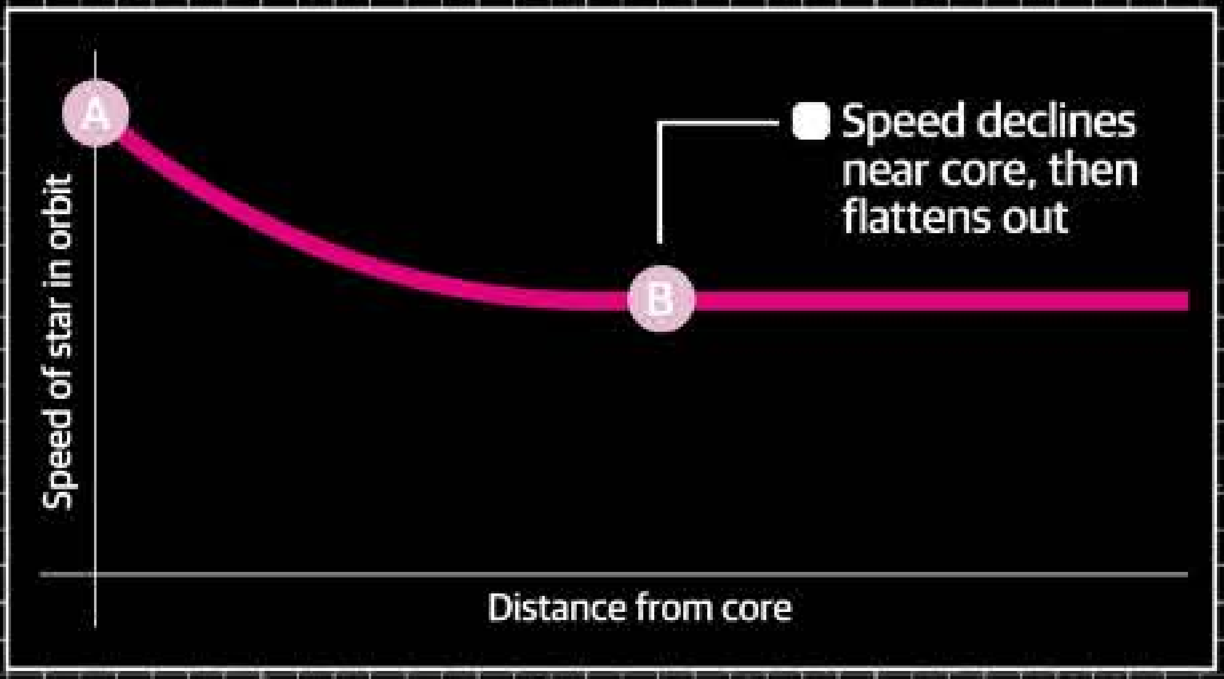
The 'dark matter paradigm' suggests that galaxies are surrounded by a much heavier halo of dark matter, whose gravity influences the orbits of stars further from the core.


'Halo' of dark matter with rotating galaxy embedded near the centre.



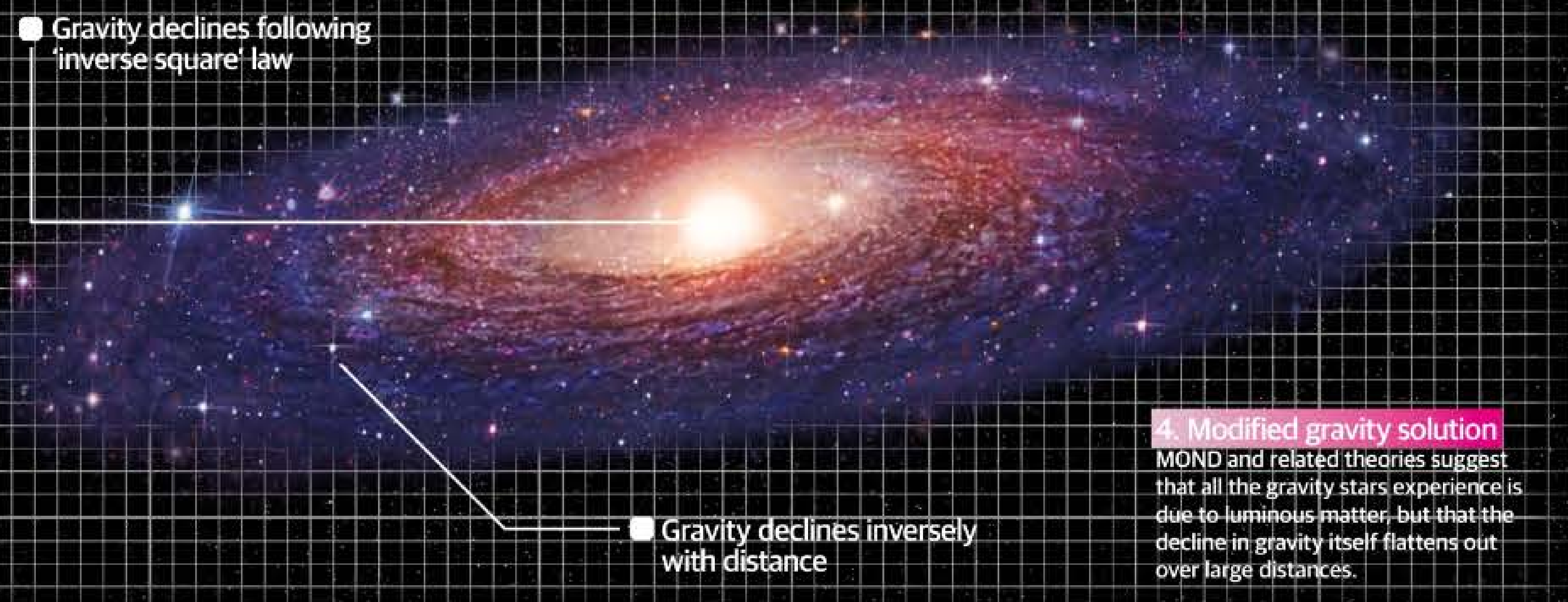
2. Expected motion

If a galaxy's mass matched its distribution of luminous matter, then Newtonian gravity suggests that stars should orbit more slowly at greater distances from the core.



3. Real orbits

Measurements by astronomers show that, beyond a certain distance from the core, stars all tend to orbit at a certain speed, suggesting they are experiencing unexpectedly strong gravity.


Gravity declines following 'inverse square' law
Gravity declines inversely with distance

4. Modified gravity solution

MOND and related theories suggest that all the gravity stars experience is due to luminous matter, but that the decline in gravity itself flattens out over large distances.

© Nicholas Forder

What if, some argued, the laws of Newtonian gravity were not as rock-solid as generally thought? In 1983, Israeli physicists suggested that the problem would disappear with a relatively simple tweak to the puzzlingly way that gravity tails off over the largest of cosmic distances.

Newton's equations suggest that the strength of gravity declines according to an 'inverse square law' - doubling the distance between two masses reduces the gravity between them to a quarter of its former strength. Milgrom's 'modified Newtonian dynamics' (MOND) theory suggested that at great distances, when the acceleration due to gravity becomes 100-billion-times weaker than we experience on the surface of the Earth, its decline becomes a simple inverse relationship (where doubling the distance halves the strength). If one relationship changed gradually to the other on scales of tens of thousands of light years, then gravity above these scales would be much stronger than Newtonian predictions, explaining why stars in the outer reaches of galaxies move so fast.

However, MOND itself is simply a 'paradigm' - a framework for thinking about the problem. Over the following years, Milgrom and his colleague Jacob Bekenstein worked to develop it into a complete theory where the equations match up precisely to the evidence observed from galaxy rotation curves.

Developing a form that can work even in the extreme situations of general relativity took considerably longer, but in 2004, Bekenstein produced 'tensor-vector-scalar gravity' (TeVeS) theory, a model of gravity that can, at least in theory, replace both Newtonian gravity and general relativity.

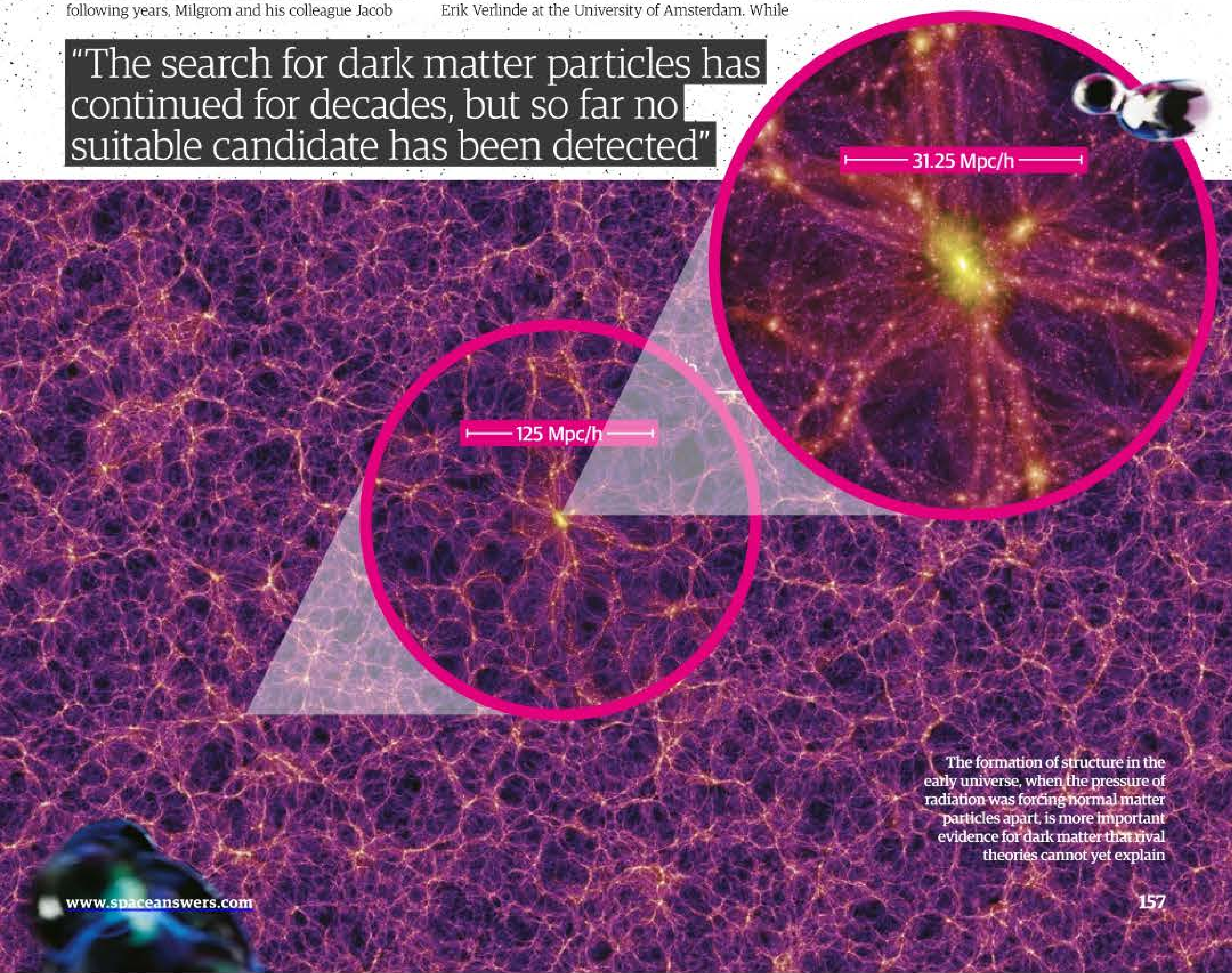
But, despite these advances, MOND remained on the fringes while most astronomers chased after dark matter. Supporters picked away at areas where the dark matter paradigm seemingly failed to match observations of the real universe, but MOND was also vulnerable to such criticisms. And even when TeVeS emerged as a possible description of how gravity might work, it didn't really explain why it would work that way.

In the past decade, however, that has changed with the emergence of a new theory called 'emergent gravity', pioneered by theoretical physicist Erik Verlinde at the University of Amsterdam. While previous theories were driven by the need to explain galaxy rotation curves, Verlinde's work started out as a way of looking at the biggest problem in modern science.

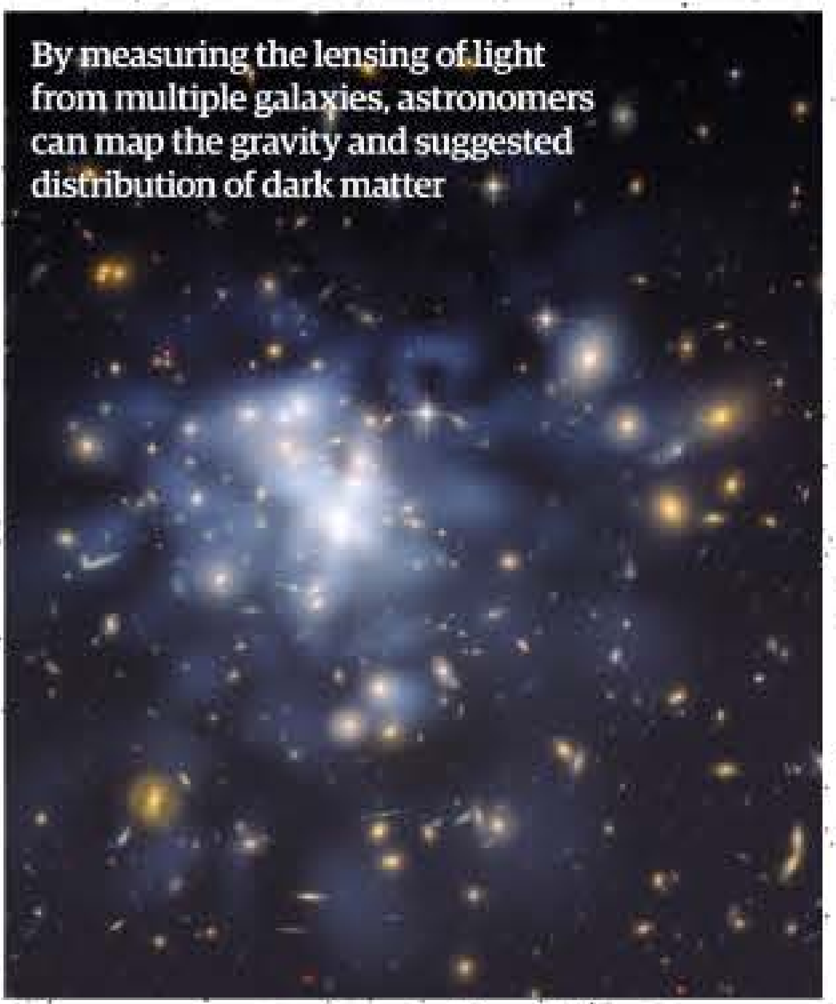
"In physics we have two great theories, explains Margot Brouwer, "Einstein's general relativity explains everything on large scales, and quantum mechanics works to explain the very small scales of atomic nuclei and elementary particles. But, when we try to combine the two scales, the equations don't work out, and so far nobody's been able to make a theory that combines general relativity with quantum mechanics."

Verlinde's theory is too complex to explore here in detail, but at its heart is a description of how complex quantum phenomena link separated areas of space-time to create the 'emergent force' that we experience as gravitation. On relatively small scales, gravity in Verlinde's theory behaves just like that of Newtonian physics and general relativity – the only significant difference is that, as the strength of

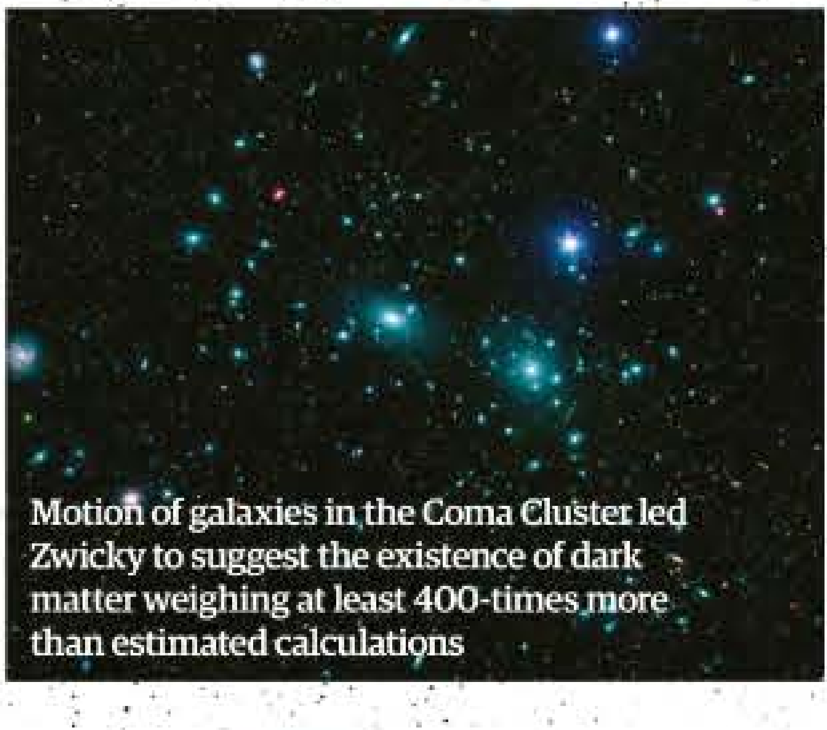
"The search for dark matter particles has continued for decades, but so far no suitable candidate has been detected"



The formation of structure in the early universe, when the pressure of radiation was forcing normal matter particles apart, is more important evidence for dark matter that rival theories cannot yet explain



By measuring the lensing of light from multiple galaxies, astronomers can map the gravity and suggested distribution of dark matter



Motion of galaxies in the Coma Cluster led Zwicky to suggest the existence of dark matter weighing at least 400-times more than estimated calculations

gravity trails off over huge distances, the pattern of its decline changes from an inverse-square law to a simple inverse relationship - the same pattern used by MOND theories.

Any scientific theory should make predictions that can be tested, and for Brouwer, Verlinde's prediction was too tempting to ignore. Luckily, her research interests provide her with an ideal situation in which to test it. "My main research topic is studying the distribution of gravity around galaxies, and the way that we do this uses a phenomenon called weak gravitational lensing. Einstein's general relativity shows that gravity is essentially the same as curvature of space-time, so when light from a distant galaxy passes through space-time that is curved by the mass of another galaxy, the light from the more distant galaxy will get distorted."

Brouwer's work involves measuring the distortion of light from many different background galaxies, as it passes a single foreground system. This allows her to map the distribution of mass and gravity, but it does also mean taking the elusive dark matter into account: "In the dark matter paradigm you would have the galaxy surrounded by a cloud of dark matter - you can approximately know the mass of the visible galaxy, but it's not easy to predict the mass of the dark matter cloud - often that's what we're trying to figure using the gravitational lensing method."

Verlinde's ideas, however, provide an opportunity to turn Brouwer's usual methods on their head. "The theory gives a prediction for how the gravitational distortion around a galaxy will be distributed based on the mass of visible stars and gas in that galaxy. Dark matter does not exist, so all the gravity originates from the normal matter, and we can work out the distribution of gravity around the galaxy and the space-time distortions arising from that. That's what I calculated, and when I compared that to measurements of the gravitational lensing effect, to my surprise they were in fact an exact match."

When the findings were published last year, some observed that traditional dark matter models could also produce a good match for the observed lensing effects - but Brouwer explains that's missing the point. "In the dark matter model you can change the percentage of dark to visible matter for each individual galaxy, which makes it easier to adjust the gravity and match perfectly with the lensing effects you detect. Verlinde's model makes a more direct prediction with none of these 'free parameters', and the fact that it matches so well immediately grabbed my attention."

But while the Verlinde theory may have cleared this first hurdle in style, there are still many problems in thinking that some form of MOND could easily replace dark matter. As mentioned

"So far nobody's been able to make a theory that combines general relativity with quantum mechanics" **Margot Brouwer**

For dark matter

Fritz Zwicky (in Helvetica Physica Acta, 1933)

"If [my estimate of the Coma Cluster's mass] is true, then the surprising result would be that dark matter is present in much greater density than glowing matter."

Michio Kaku, City College of New York

"I hope we find evidence of dark matter in the lab and in outer space. This would go a long way to proving the correctness of string theory, which is what I do for a living."

Chamkaur Ghag, University College London, chair of the Dark Matter UK consortium

"Theory indicates we have a really good chance of finding dark matter particles. This is certainly not the time to talk of giving up. Are we just going to say 'OK, we have no idea what makes up 85 per cent of the universe just because we are finding it all a bit hard'? That's not realistic."

Kathryn Zurek, Lawrence Berkeley National Laboratory

"As evidence for dark matter, [galactic rotation curves are] only one very small part of the puzzle. Dark matter explains a whole host of observations from the time of the cosmic microwave background when the universe was just a few-hundred-thousand-years old, through structure formation all the way until today."

© NASA; UCL; Cristiano Sant' Anna; Roy Kaltschmidt/Berkeley Lab; John Moffat; Weizmann Institute of Science; M.McCaughrean (ESA)/ESO

above, the dark matter paradigm is supported not just by galaxy rotation, but in complex situations such as galaxy cluster collisions (where dark matter appears to separate from the luminous matter) and the early days of the universe (where dark matter began to clump together and form the beginnings of today's web-like cosmic structure while luminous matter was still in chaos).

Unfortunately, it's just too early to know whether emergent gravity might have its own solutions to these sorts of observations, as Margot Brouwer explains. "One of the main criticisms of Verlinde's theory from an observational point of view is that it can only make fairly rudimentary predictions for spherically symmetric, static and isolated mass distributions. Because I was studying lensing around individual galaxies that aren't doing too much crazy stuff, I was able to test Verlinde's theory for this particular case. But, so far, the theory can't make predictions for more 'messy' situations."

Erik Verlinde is now working on extensions of the theory that could explain how gravity works in more complex conditions, but it could be many years before that work comes to fruition. In the meantime, as Brouwer points out, the case is far from proven. "Just because I worked on Verlinde's theory, that certainly doesn't mean I don't believe in dark matter. There are a lot of challenges still, and of course there's still a hope that one day they'll track down dark matter particles (though they've been looking for a very long time!). "There are all kinds of strange things going on in the universe where we absolutely seem to still need it, so I certainly wouldn't say that dark matter is dead."

For now we can only wait for theorising and testing to be done.

Some astronomers claim that the orbits of small satellite galaxies around the Milky Way are better explained by MOND than by dark matter

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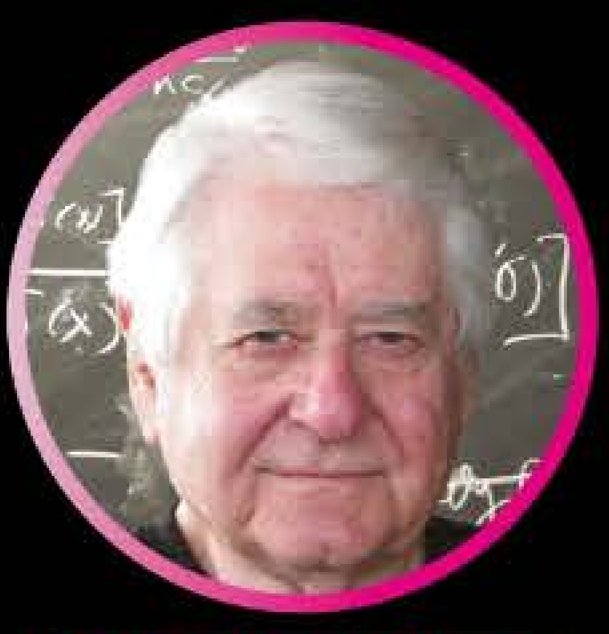
Against dark matter

Vera Rubin in *One Hundred Years of Rotating Galaxies* (Astronomical Society of the Pacific, 2000)

"Surprisingly, we cannot yet rule out a modified gravitational potential, rather than dark matter, as the explanation of our observations. We have learned much about galaxies in the last 100 years. I think that we still have major surprises to uncover."

Pavel Kroupa, University of Bonn

"The existence of dark matter particles can never be disproven by direct experiment because ever lighter particles, and/or ever smaller cross sections just below the current detection threshold may be postulated for every non-detection. There exists no falsifiable prediction concerning the DM particles."



John Moffat, University of Toronto, in his book *Reinventing Gravity*

"It may be that ultimately the search for dark matter will turn out to be the most expensive and largest null-result experiment since the Michelson-Morley experiment [an 1887 experiment that failed to find the hypothetical ether substance supposed to fill space]."

Mordehai Milgrom Weizmann Institute of Science, Israel

"Recent years have seen the advent of several relativistic formulations of MOND. These account well for the observed gravitational lensing, but do not yet provide a satisfactory description of cosmology and structure formation... [I]t may well be that none of them point to the correct MOND theory."

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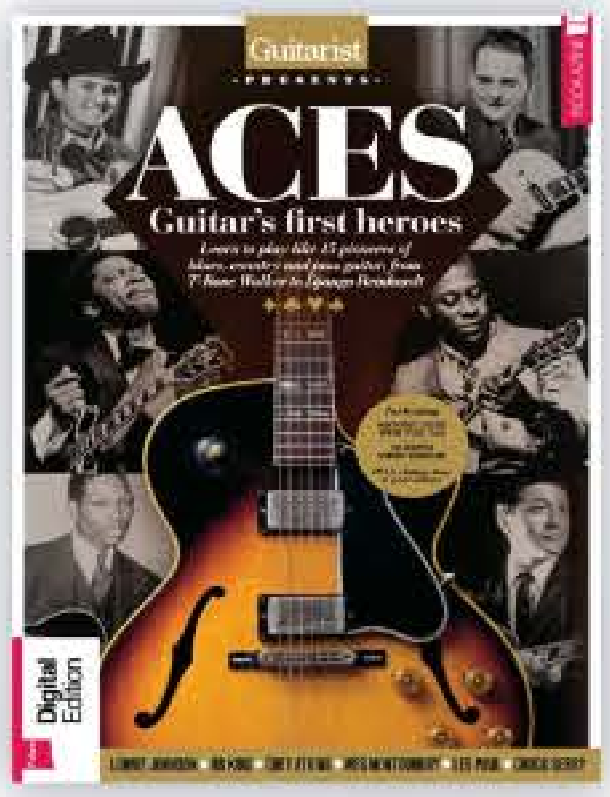

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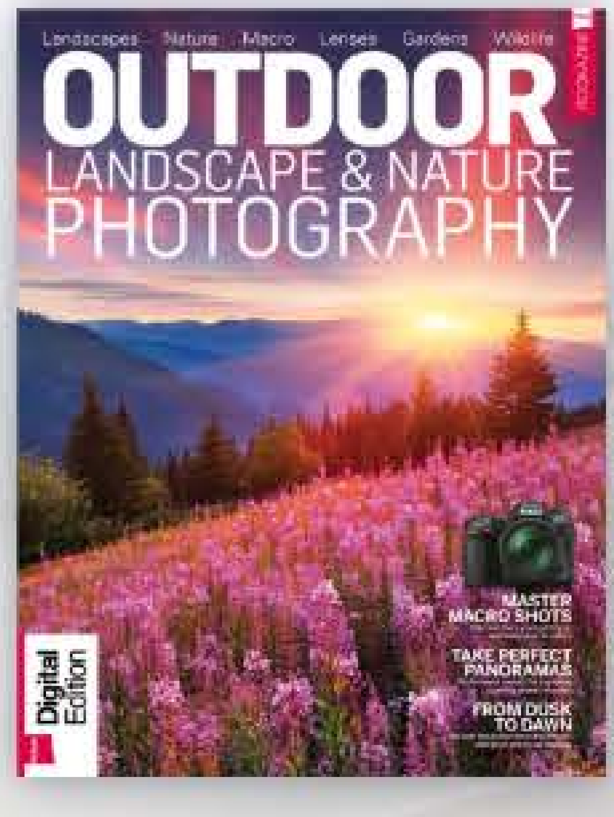

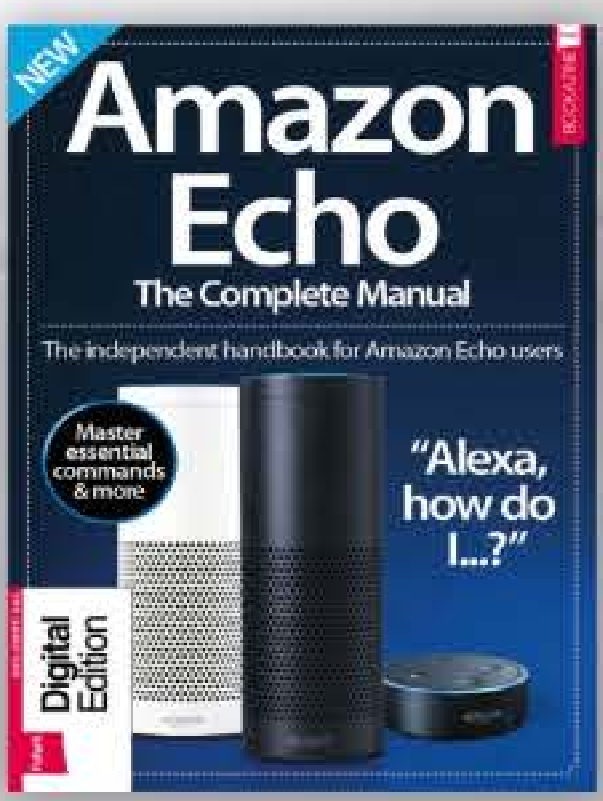

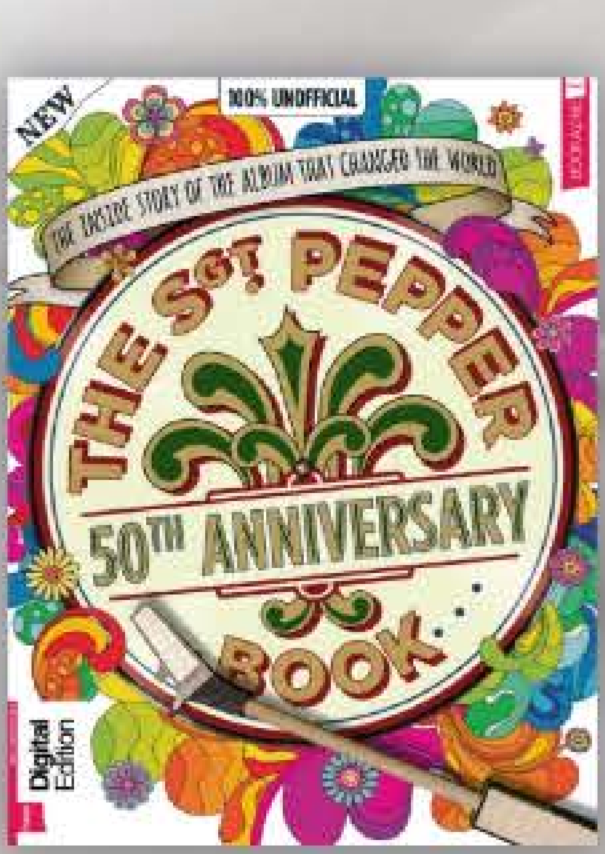

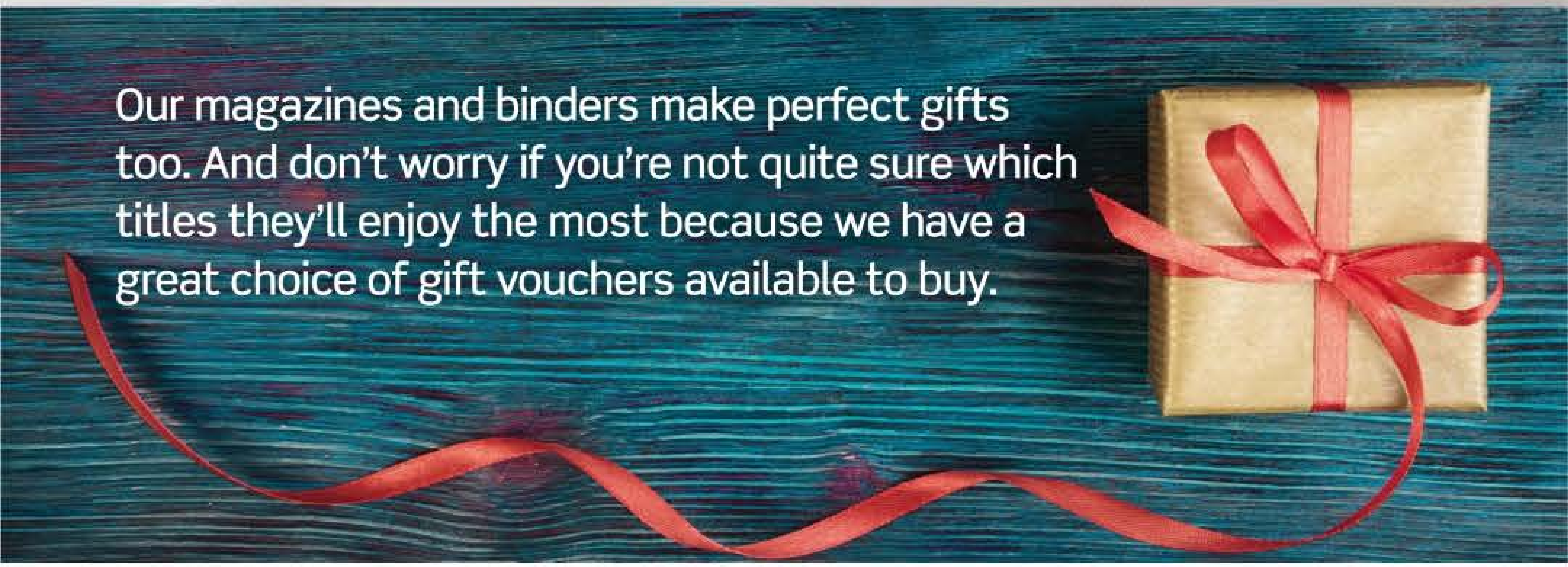

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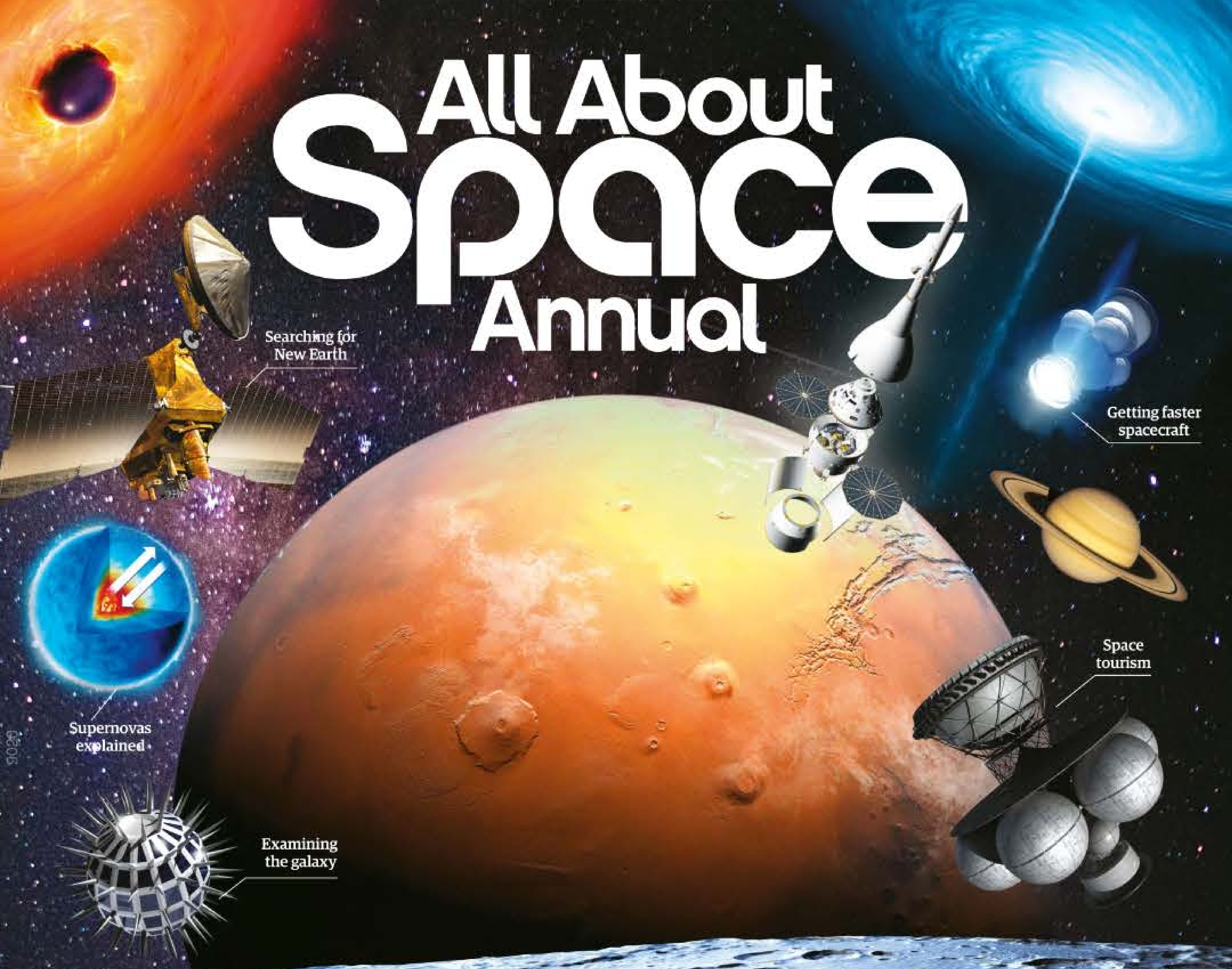

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